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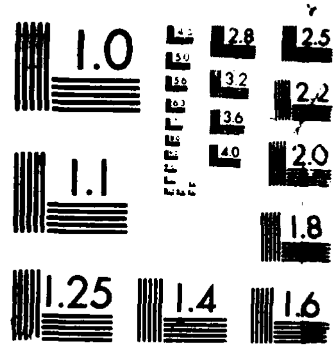

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ARCHITECTURE OF AN EXPERT SYSTEM FOR
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Stephen L. Wood and Richard A. Skop

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Naval Ocean Research and Development Activity

Department of the Navy

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Methods for the design and analysis of oceanographic moorings are well established (Berteaux, 1976). However, as with most engineering design problems, there are certain "rules-of-thumb" or "tricks-of-the-trade" that streamline the design process and enhance the performance of the final product. These rules-of-thumb are normally known to only a small cadre of people -- experts -- who have deep involvement and experience in the particular engineering design problem. These rules-of-thumb and other knowledge of several experts are incorporated to develop the fundamental architecture of an expert system for the design of single-point, subsurface, oceanographic moorings. Such moorings are used worldwide to collect oceanographic and acoustic data. The projected end user of this expert system is the oceanographer or acoustician who wishes to design and/or cost out a mooring but hasn't the access to, or support for, a mooring design group.

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1.0 Introduction:

Single point subsurface mooring development traditionally is performed by an expert using basic algorithmic programs to facilitate and analyze the developed design see, for example, Moller [1976]. Computer programs have not yet been created to take over the mooring design process, thereby freeing the expert from much of the standard design process or allowing the non-expert to develop a functional mooring. An expert system fulfills this purpose by incorporating the design knowledge of experts together with data bases of state-of-the-art mooring components and instrumentation. With a mooring development expert system the scientist (non-expert) is relieved of some large expenses accrued in the design of a mooring system while also developing a reliable mooring design. An expert system allows the scientist easy access to expert information even when an expert is unavailable. An expert system also accelerates the design process for both the expert and non-expert.

The expert system encompasses all aspects found in a typical sub-surface mooring design -- preliminary or conceptual design, analysis, tradeoffs and re-analysis, and finally a detailed design. The scientist utilizing the system is relieved of the many complex issues incorporated in the design. His input is limited to his basic needs (such as the geographical location of the mooring, the types and desired depths of his sensors, motion restrictions on

the sensors) and the essential needs of the expert system (such as water depth, expected currents, and bottom type) that are not currently available in a data base. The expert system performs the selection of the mooring components from various data bases and rules-of-thumb along with the structural analysis, cost analysis, and feasibility studies. If any of these cause failure in the design of the mooring, the user is informed along with possible tradeoff solutions necessary to achieve a satisfactory solution/design. The user then may make these or other tradeoffs and have the expert system check these new parameters for viability. In general, the expert system acts as an explanation system, knowledge system, knowledge base, analysis base, and inference engine -- that is, it acts as an expert mooring designer or mooring design group. The use of an expert system shell was necessary since shell development is beyond the scope of this project. Insight 2+ expert system shell [Insight 2+ Reference Manual, 1986] was used for our application.

2.0 Mission Requirements

To generate the least expensive, functional, and reliable single-point subsurface mooring design is the primary purpose of the expert system. Primary mission requirements encompassed by the mooring expert system include the following:

- Acoustic and non-acoustic arrays.
- Standard range of depths utilized by most mooring

arrays (30 meters to 6000 meters).

- Any range of currents.
- Selection of state-of-the-art instruments and utilization of state-of-the art and standardized equipment.

The system assumes the design engineer or user has none of the mooring equipment and will be purchasing the necessary components. Secondary Objectives are to:

- enable the user to play an active role in decision-making; to evaluate and make tradeoffs to generate a satisfactory design.
- allow the user to add new or different instruments to those already contained in the system.
- enable the user to have access to the program structure through the use of an extensive explain capability with "why" and "explanation facilities".
- give a cost analysis of the design
- provide a report on the design in a directly usable format along with a parts list and price list.
- provide a graphic output; giving the designer standardized drawings on the components, instruments and information of the design.

3.0 Constraints on the Expert System:

Only state-of-the-art equipment and standard items found in manufacturing inventory are utilized in this expert system, leaving specialized equipment to the user or design

engineer. Maximum and minimum constraints of equipment are restricted by the utilization of such standardization. This allows for the use of standard size machinery, wire spools, pulleys, winches and other equipment employed in a standard deployment.

The design is based on anchor-last deployment method. That is, the uppermost floats, instruments, and line are paid out under moderate tension until the lower end of the mooring is reached. The anchor is finally attached and allowed to free-fall to the bottom.

The maximum depth utilized by the system is 6000 meters, which is the maximum depth of the ocean floor excluding the very deep trenches. The minimum depth is 30 meters, which is the minimum limit of moderate wave effects.

The maximum deployment time is three (3) years. The three year limitation is due to insufficient information on extended deployments. Beyond this time limit the reliability of the mooring is unknown. If longer periods are needed it is recommended to use the maximum limit for a preliminary design and have it analyzed by an expert for reliability in that specific deployment case.

Both metric and the English systems are used in a mooring system. The depth is usually in meters, velocity of the current is in either centimeters per second or knots, buoyancy is in pounds. The scientist uses cm/sec but the ship captain uses "knots". All other calculations are in English. Output is available in either or both units.

4.0 Methodological flow of a subsurface mooring design

Utilizing the basic design strategy of a typical engineering problem [see Figure 1] most of the processes once done by the expert are now accomplished by the expert system [see Figure 2]. This relieves the expert design engineer or the non-expert user of the most tedious research and development aspects of mooring design. The expert system attempts to satisfy the mission requirements of the design, make suggestions for possible alternatives when a design isn't possible, and also allow the user to make tradeoffs.

The basic line of design development starts from the preliminary engineering requirements developed by the expert system in responding to user requirements, along with the many constants found at the mooring deployment site. Once the preliminary requirements and information are gathered, a conceptual design is generated. The conceptual design is a very rudimentary design for the computer's use only and initiates the design process. Following the conceptual design a preliminary design is generated. The preliminary design, in many cases (for example, weak current regions with few to no restraints on the system), satisfies most or all of the requirements of the design. If the design requirements are satisfied, then a detailed design is generated. If the requirements are not satisfied after the expert system exhausts all possible solutions, the preliminary design is modified with the help of the user in

making tradeoffs, until a satisfactory solution is obtained. The modified solution is then analyzed for performance. With the detailed design completed, a cost analysis is done on the design to obtain a final cost estimate along with an individual component cost estimate report in 1987 dollars. If the cost is not agreeable with the design engineer, suggestions can be made of possible tradeoffs and a redesign performed. Once the user is satisfied with the solution, a production design is generated with a complete report of all equipment used.

5.0 Expert System Utilization

An expert system must have various features to make it suitable for the application of mooring design. These components are: User Interface; Explanation System; Knowledge System; Knowledge Base; Inference Engine; Working Memory /Blackboard; and access to external programs and data bases [Glossary : Appendix B].

The use of an Expert System Shell (Knowledge System Building Tool) reduces the difficulty of designing and implementing an expert system. The shell possesses the features listed above but implements them in a general form which can be used for many different applications. There are various pros and cons found in the use of a shell. Designing an expert system with the use of a shell speeds up the development time significantly. The shell provides tools that ease the task of implementation by the use of rule editors and diagnostic aids. The shell also presents a

methodology of thinking about the problem as well as analysis. The shell "can become not only a tool of convenience but also a tool of thought" [Sell, 1985]. In contrast, the expert system is often restricted by the limitations of the shell. Another difficulty encountered is propriety of the system. An expert system developed with the use of a shell is useless without that shell, so in order to distribute the system copyrights or licenses must be obtained. Support of the shell by the commercial vendor must be carefully reviewed since some vendors provide support, training, and documentation, while others provide minimal assistance to their product [Harmon & King, 1986]. Similarly, the descriptions of the shell's capabilities must be examined, for some vendors take great liberties in their descriptions of their system's abilities. If the shell is researched, and tested to be adequate for the design at hand, then one can implement a system expeditiously.

Before attempting to build the system, a model of the decision tree (expert system flow chart, appendix C) allows the knowledge engineer to have an idea of the knowledge base and the inference process, along with defining the item relationships with the expert. Many basic questions are addressed in order to minimize design mayhem [Harmon & King, 1986] and [Taylor, 1986]:

- How is the knowledge acquired?
- How is the knowledge represented?
- How are the knowledge representations to be

implemented on various types of hardware?

- How is the knowledge accessed inside the expert system?
- How is the knowledge applied to a particular situation?
- How is the knowledge modified when new knowledge is obtained?
- How is the knowledge to be maintained?
- How is the final result to be presented?
- Is the system assisting or replacing the expert?
- How often will external data bases be accessed?
- Should information be volunteered to the user?
- Should the knowledge base be understandable to the expert?
- How much explanation should be given to the user?
- What type of results/reporting facilities are required?
- Does the knowledge information have elements of uncertainty?

Whether one uses an expert system shell or develops his own, there must be an interface to external programs/languages (FORTRAN, PASCAL, C etc.). Access to data bases is one of the most important aspects in an expert system. It is essential that a large system be able to run in small steps, thereby storing data from previous runs and restarting at will [Taig, 1986].

A list of the components that should be found in the

expert system shell to be used in the mooring design are as follows: [Harmon & King, 1986]

In the **knowledge** domain:

- Facts:

  - Object-Attribute-Value Triplets.

    An object is an actual or conceptual element in the domain of the user. Attributes are properties affiliated with objects. They can represent multiple objects and use inheritance hierarchies (for example, coefficient of drag is an attribute of a glass ball with a value of 1.2)

  - Attribute-Value Pairs. An Attribute is a property affiliated with a specific object. Similar to O-A-V pairs methodology except that they cannot represent multiple objects or use inheritance hierarchies and in a rule the reference to an object is omitted. (For example, maximum slope < 15°)

- Relationships

  - IF-THEN Rules

- Uncertainty

- External Programs and Procedures

In the **inference** domain:

- Generating New Facts

  - Modus Ponens A logic rule that implies if we know A implies B, and we know A is the case, then we can assume B.

- Control Strategies
  - Backward Chaining
  - Forward Chaining
  - Depth-First Search
  - Breadth-First Search
- Controlling sources of data from the knowledge domain

In the **interface** domain:

- Knowledge Engineer
  - Trace and Probes
  - Knowledge domain editor (additions or replacements)
- User
  - Queries
  - Prompt-Menu Display
  - Explanations and Justifications

Other features can be added to this list depending upon the usage intended for the system. The conceptual design of the mooring expert system is given in Figure 3.

6.0 Mooring\Buoy Design

To design the initial architecture, one must first determine the method of designing a buoy system. Two basic methodologies in the design of a mooring/buoy system are presented by the experts:

1) The instruments for the experiments are separated from the assembly and the cable characteristics computed (ie. below 2000m there is Kevlar Rope of breaking

strength X1 and above 2000m there is wire rope of breaking strength X2). The designer then locates his experiments at the desired depth. The rope is then broken down into two smaller segments and reduced in length to accommodate the length of the instrument. This is continued until all of the instruments are taken into account.

2) Each individual component is taken into account and a "top down" line of approach is generated. Each part contains an identification number and a data base of all the other information on that individual component. At the finish one has a list from 1 to N components and their properties.

For the implementation of an Expert System a combination of these two methodologies must be incorporated. An iterative process with component selection and analysis with the combined methodology above, creates the design procedure of an expert. To analyze and implement an Expert System method, the types of moorings must first be classified. This reduces the complexities of the number of possible mooring variations encountered by traditional designs. The classifications are broken into twenty-eight (28) different types. Fourteen (14) types are for acoustic arrays which require an electromechanical, strumming suppressed cable component. The other fourteen (14) types are for non-acoustic arrays for which standard ropes are used. Within these two broad classes, the other classification criteria utilized are:

- Are the instruments in a strong or weak current region?
- Is the depth of the top buoy above or below 500m (crush depth for steel or aluminum spheres)?
- Is the ocean depth less than or greater than 2000m (shark bite depth region)?
- Is the deployment in the shark bite zone (40°N to 40°S)?

A typical rule in the determination of classification is [see Figure 4]:

RULE NonAcoustic mooring type 4A
IF NonAcoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
AND Top experiment depth <= Shark bite zone
THEN We have the type of mooring
AND Clump anchor
AND Chain above anchor
AND Nylon shock line
AND Wire rope anchor
AND Chain below acoustic release
AND Acoustic releases
AND Chain for retrieval
AND Glass balls for retrieval
AND Kevlar rope
AND Wire rope
AND Chain for primary retrieval

AND Glass balls for primary flotation

AND Polypropylene rope

AND Chain for recovery aids

AND Glass balls for recovery aids

AND Instruments

AND We have the materials

7.0 Classification: [Figures 5,6,7 and 8]

7.1 Non-Acoustic arrays:

7.1.1 Weak Currents:

1A) Location between 40°N and 40°S, Maximum Depth 2000m with top experiment at 500m or less, Steel Wire Rope, Steel Sphere or Glass Balls, Glass Balls as backup flotation, Release.

2A) Location between 40°N and 40°S, Maximum Depth 2000m with top experiment below 500m, Steel Wire Rope, Syntactic Foam Sphere or Glass Balls, Glass Balls as backup flotation, Release.

3A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment above 500m, Steel Wire Rope above 2000m and Kevlar Rope below 2000m, Steel Sphere or Glass Balls, Glass Balls as backup flotation, Release.

4A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 500m but above 2000m, Steel Wire Rope above 2000m and Kevlar

Rope below 2000m, Syntactic Foam Sphere or Glass Balls, Glass Balls as backup flotation, Release.

5A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 2000m, Kevlar Rope below 2000m, Syntactic Foam Sphere or Glass Balls, Glass Balls as backup flotation, Release.

6A) Location north of 40°N or south of 40°S with top experiment above 500 meters, Kevlar Rope, Steel Sphere, Glass Balls as backup flotation, Release.

7A) Location north of 40°N or south of 40°S with top experiment below 500 meters, Kevlar Rope, Syntactic Foam Sphere or Glass Balls, Glass Balls for backup flotation, Release.

7.1.2 Strong Currents:

(current of 1.5 Knots at any instrument or buoy)

8A) Location between 40°N and 40°S, Maximum Depth 2000m with the top experiment at 500m or less. Steel Wire Rope, Steel Sphere, Strut Fairings down to where the analyzed current profile dictates, Glass Balls as backup flotation, Release.

9A) Location between 40°N and 40°S, Maximum Depth 2000m with the top experiment below 500m. Steel Wire Rope, Syntactic Foam Sphere, Strut Fairings down to

where the analyzed current profile dictates, Glass balls as backup flotation, Release.

10A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment above 500m, Steel Wire Rope above 2000m and Kevlar Rope below 2000m, Steel Sphere, Strut Fairings down to where the analyzed current profile dictates, Glass balls as backup flotation, Release. These types are deployed in high current areas, Gulf Stream, the Straits of Gibraltar and similar locations. This mooring configuration usually requires a two buoy system if experiments are located in the high velocity current region. The larger buoy is located below the high velocity region and a smaller buoy in that region (classification 10A1). A streamlined syntactic foam buoy may also replace the steel spheres if classification 10A and 10A1 design fail. The cable section that lies within and near the high velocity region must have fairings to eliminate the drag and to reduce cable strumming.

11A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 500m but above 2000m, Steel Wire Rope above 2000m and Kevlar Rope below 2000m, Syntactic Foam Sphere, if top experiment below current then Glass Balls, Strut Fairings down to where the analyzed current profile

dictates, no Strut Fairings if top experiment is below current, Glass Balls as backup flotation, Release.

12A) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 2000m, Kevlar Rope below 2000m, Strut Fairings down to where the profile dictates, Syntactic Foam Sphere, Glass balls as backup flotation, Release.

13A) Location north of 40°N or south of 40°S with top experiment above 500 meters, Kevlar Rope, Strut Fairings where profile dictates, Steel Sphere, Glass Balls for backup flotation, Release.

14A) Location north of 40°N or south of 40°S with top experiment below 500 meters, Kevlar Rope, Strut Fairings where profile dictates, Syntactic Foam Sphere or Glass Balls, Glass Balls for backup flotation, Release.

7.2 Acoustic arrays:

7.2.1 Weak Currents:

1B) Location between 40°N and 40°S, Maximum Depth 2000m with top experiment at 500m or less, Steel E/M Cable, Hairy Fairies, Steel Sphere or glass balls, Glass Balls as backup flotation, Release.

2B) Location between 40°N and 40°S, Maximum Depth 2000m with top experiment below 500m, Steel E/M Cable, Hairy Fairies, Syntactic Foam Sphere or Glass Balls,

Glass Balls as backup flotation, Release.

3B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment above 500m, Steel E/M Cable above 2000m and Kevlar below 2000m, Hairy Fairies, Steel Sphere or Glass Balls, Glass Balls as backup flotation, Release.

4B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 500m but above 2000m, Steel E/M Cable above 2000m and Kevlar E/M Cable below 2000m, Hairy Fairies, Syntactic Foam Sphere or Glass Balls, Glass Balls as backup flotation, Release.

5B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 2000m, Kevlar E/M Cable, Hairy Fairies, Syntactic Foam Sphere or Glass Balls, Glass Balls as backup flotation, Release.

6B) Location north of 40°N or south of 40°S with top experiment above 500 meters, Kevlar E/M Cable, Hairy Fairies, Steel Sphere, Glass Balls as backup flotation, Release.

7B) Location north of 40°N or south of 40°S with top experiment below 500 meters, Kevlar E/M Cable, Hairy Fairies, Syntactic Foam Sphere, Glass Balls for backup flotation, Release.

7.2.2 Strong Currents:

(current of 1.5 Knots at any instrument or buoy)

8B) Location between 40°N and 40°S, Maximum Depth of 2000m with the top experiment at 500m or less, Steel E/M Cable, Strut Fairings down to where the current profile dictates then Hairy Fairies on the remaining cable, Steel Sphere, Glass Balls as backup flotation, Release.

9B) Location between 40°N and 40°S, Maximum Depth of 2000m with the top experiment below 500m, Steel E/M Cable, Strut Fairings down to where the current profile dictates then Hairy Fairies, Syntactic Foam Sphere, Glass Balls as backup flotation, Release.

10B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment above 500m, Steel E/M Cable above 2000m, and Kevlar E/M Cable below 2000m, Strut Fairings down to where the current profile dictates then Hairy Fairies, Steel Sphere, Glass Balls as backup flotation, Release. This mooring configuration also usually requires a two buoy system if experiments are located in the high velocity current region. The larger buoy is located below the high velocity region and a smaller buoy in that region (classification 10B1). A streamlined syntactic foam buoy may also replace the steel spheres if classification 10B and 10B1 design fail. The cable section that lies within and near the high velocity

region must have fairings to eliminate the drag and to reduce cable strumming.

11B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 500m but above 2000m, Steel E/M Cable above 2000m, and Kevlar E/M Cable below 2000m, Strut Fairings down to where the current profile dictates if top instrument is below current then Hairy Fairies, Syntactic Foam Sphere, Glass Balls as backup flotation, Release.

12B) Location between 40°N and 40°S, Maximum Depth greater than 2000m with top experiment below 2000m, Kevlar E/M Cable, Strut Fairings down to where profile dictates and Hairy Fairies on the other cable segments, Syntactic Foam Sphere, Glass Balls as backup flotation, Release.

13B) Location north of 40°N or south of 40°S with top experiment above 500 meters, Kevlar E/M Cable, Strut Fairings where profile dictates, Hairy Fairies else where, Steel Sphere, Glass Balls for backup flotation, Release.

14B) Location north of 40°N or south of 40°S with top experiment below 500 meters, Kevlar E/M Cable, Strut Fairings where profile dictates, Hairy Fairies else where, Syntactic Foam Sphere, Glass Balls as backup flotation, Release.

8.0 REGIONS

There are three regions in the ocean which must be taken into account in the Expert System. Each of the three regions has specific design criteria which determine the type of mooring to be used. Each region has its own current profile which differs quite substantially from the other two. These regions are: Continental Shelf, Continental Slope, and Floor.

1) The Continental Shelf region (Shallow Zone) which tends to be approximately 130m deep over most of the world's oceans, but are found as deep as 350m in areas around Antarctic. Slopes on the shelf tend to be very mild, less than 1:1000 [Kennett, 1982].

2) The Continental Slope (Intermediate Zone) which continues down to 1500-3000m. The slope is steep with an average slope of 4 degrees, but there are places with slopes ranging from 35 to 90 degrees [Kennett, 1982].

3) The Floor "Deep Zone" (for our case this includes the continental rise) lies below 3000m and has a seaward gradient of 1:100 or less [Kennett, 1982]. In the regions away from the Gulf Stream the surface and deep currents are rarely coplanar, but averaging the data over a year the mean mass transport is found to be directional and allows for an equation to be established [Berteaux, 1970]. If the designer doesn't have the current profile information then utilizing this "canned" equation gives the designer an idea of

what mooring system can be used without great error.

In the Shallow and Intermediate Zones the variation in current profiles is such that any "canned" profile, for the cases where the designer hasn't any idea of the currents at the deployment site, would be unrealistic and contain an extreme probability of error. The Scientist/User of the expert system must know the profile information for these regions. Deep Zone areas within the Gulf Stream have a constant speed layer, if the scientist knows the depths of the constant speed layer, a "canned" routine has been developed for these regions.

9.0 Canned Profile Equations:

For the Deep Zone the equation of the current profile in the Deep Zone is given by the equation [Berteaux, 1970]:

$$u = 2.52 * U_s d^{-.4} \quad \text{[Webster]}$$

u = speed at depth d

$d > 10$ meters

U_s = surface current which is assumed constant down to 10 meters.

The user need only to enter the surface velocity, the expert system using this information produces a hypothetical velocity profile.

If the mooring is in the Gulf Stream and the depth of the constant speed layer is known or can be hypothesized the the average Gulf Stream instantaneous current profiles can be expressed by [Berteaux, 1970], also see Figure 9:

$$u = d_o^m * U_s * d^m$$

d_o is the depth of the constant speed layer.

m has been observed to vary between -.28 and -.42

One point of caution, it has been found that bottom currents as far as 100 miles from the Gulf Stream, may reach velocities as great as 20 cm/sec [Berteaux, 1970]. Woods Hole Oceanographic Institute has recorded at 40° North, 42° West, velocities of 75 cm/sec at 5000 meters. At 37° North, 68° West, velocities of 40 cm/sec were recorded at 4000 meters depth over a period of a week and reducing as the depth lessened [S. Kerry, WHOI Engineer, personal communication, May 15, 1987]. It must be stressed that "canned" profile equations when used in a general program may present an inaccurate profile which can lead to large errors in the design.

10.0 Design and Survival Current Profile:

For each design of a subsurface mooring system, two current profiles must be taken into consideration: the Design Profile and the Survival Profile.

The Design Profile for sub-surface buoys is the average current profile for a given region or geographical location over a period of time. Because of the lack of a current profile data base, the user must furnish the expected average current profile: surface velocity; highest velocities encountered; and velocities at any location available, preferably in regions of interest. If profile

data isn't available and the deployment is in the Deep Zone, the "canned" profile can be generated by the expert system. Currently the profiles can only be obtained through tedious research of existing profiles that have been accumulated throughout the scientific community.

The Survival Profile for sub-surface buoys is the maximum current profile for a given region or geographical location. If no maximums are known for a region or the profile is generated by the expert system, a survival profile is taken as twice the design profile.

The current profile entered by the user is necessary to insure a reliable design. Computer generated Deep Zone profile is an estimated profile which will be less reliable than a profile generated by experimental data. A complete set of current profile information in the future should be compiled and implemented into the Expert System. Once this profile information is implemented, all the Designer must do is specify the latitudinal and longitudinal coordinates to have the information immediately accessible to the Expert System.

11.0 Rules-of-Thumb:

Many "rules-of-thumb" or "tricks-of-the-trade" are used in the design process of a sub-surface mooring system. These "rules of thumb" must be implemented in such a way that the user can access the reasons behind their implementation in a program. The following are some of the necessary "rules of thumb" and were obtained from H. O.

Berteaux (personal communication, February 17-19, 1987) and D. A. Milburn (personal communication, May 5-7, 1987), except where noted:

1) 3 to 5 meters of chain is positioned under acoustic releases and 0.5 to 1 meter of chain below the flotation spheres.

   A) To prevent fouling of the releases and flotation spheres with the mooring line.

   B) To facilitate in the deployment of the mooring. Cables in these locations can be expected to have a significant increase in failure upon initial deployment due to chafing, fouling, or strain.

2) Approximately 5 meters of chain is positioned above the anchor.

   A) To prevent the anchor from breaking loose from the system upon the launching of the anchor due to high forces or abrasion.

   B) To protect from dragging the cable on the ground.

3) Chain is used at the location of the glass balls.

   A) Chain is used to facilitate attachment, deployment, and retrieval of the balls.

   B) With chain there is less chance of severing the cable when implosion occurs by a glass ball.

4) Approximately 20 meters of nylon rope is positioned above the chain directly over the anchor.

   A) Nylon is used at this location to relieve some of

the strain generated by: 1) the deployment fall; 2) the impact of the anchor; 3) the continued fall of the system; and 4) the resultant jerk caused by the buoy at the final setting. Nylon also helps to prevent the wire rope from becoming kinked at the jerk moment. The elastic properties of nylon allow for these uses. In depths less than 2000 meters the length should be shortened to 10 meters or eliminated to reduce the chance of fishbite.

5) Wire rope is used above 2000 meters depth.

A) Wire rope is necessary above 2000 meters due to a high probability of shark/fish bite . The shark bite region is from 40 degrees North to 40 degrees South. The chances of shark bite beyond those regions exist but the probability is negligible [see Figure 10,11,12 Berteaux, 1987].

6) Kevlar is used below 2000 meters depth.

A) Kevlar has a high strength and currently is fairly close in cost to wire rope for the equivalent strength characteristics.

B) Kevlar has almost neutral buoyancy, thereby allowing a smaller retrieval buoyancy to be necessary.

C) Kevlar is also much easier to handle in deploying and retrieving a mooring system.

7) Wire rope is used below the chain which is below the acoustic release.

A) The wire rope acts as part of the anchor, thereby

helping to reduce the size the anchor. This reduces the probability of damage caused from the jerk and tension forces at initial deployment when the anchor is falling and when it has completed its fall.

8) Fairings are used down to near zero velocity depths to reduce drag.

A) Fairings are placed closely together down to the depths where there is very little or no current. In general the amount of fairings is dictated by the current profile. If there are currents at different depths of on the whole system then fairings at those or all locations are necessary to reduce drag.

B) Acoustic moorings also have fairings down to no current regions but then require strumming dampening devices to eliminate vibrations generated by mild currents. These strumming dampening devices are Hair or Ribbon. Each of these reduce strumming in a cable but increase drag by an amplification factor α [see Table 1].

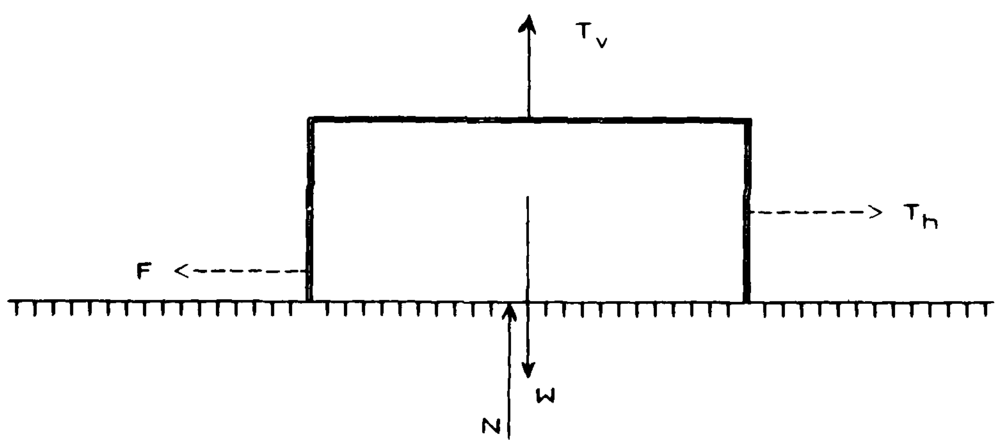
9) A Delrin ring (stacking ring) should be positioned after every five fairings.

A) This is to prevent piling and stacking of the Strut Fairings [for closer analysis on stacking see, Henderson (1978)]. This Delrin ring is many times developed "in house" and can be substituted by an equivalent spacer. This ring is usually ½ inch in length.

10) The minimum distance of the top float to the first experiment should be 5 to 10 meters. For acoustic arrays the distance is 15 meters.

A) The minimum distance is actually one buoy diameter but this not generally done for deployment reasons.

11) The anchor weight should be equal to twice the horizontal force on the anchor plus the vertical force on the anchor. If there is no horizontal force then the anchor weight equals the vertical forces plus 500 (lbs.). This "rule-of-thumb" has been very successful at Woods Hole Oceanographic Institute.



$F = \mu N = 0.5\ N = T_h$

$(\ 0.5 * (\ W - T_v\ )) = T_h$

$W = (T_h\ /\ 0.5) + T_v$

$W = T_v + \text{Max}(500\ \text{lbs.},\ (2 * T_h))$

F = friction force of anchor

μ = coefficient of friction

W = weight of anchor in water

N = normal force opposing the weight of the anchor

T_v = vertical force by the cable on the anchor

T_h = horizontal force by the cable on the anchor

Mild current : Clump anchor of weight W (deadweight).

Strong current : Mace anchor of weight W (deadweight with embedment flukes).

11A) When the anchor is on a slope the weight of the anchor to resist the tension is given by the equation [Berteaux, 1976]:

$$W = T_v + T_h \left[\frac{\mu \sin(\theta) + \sin(\theta)}{\mu \cos(\theta) - \sin(\theta)} \right]$$

where,

μ = coefficient of friction [see Table 2]

θ = angle of inclination of bottom

12) Pear-sling-links are used in joining the two shackles which are attached to the cables and instruments [see Figure 13].

13) To help in overcoming the tendency of the system to rotate, causing kinking in the cable, a swivel is sometimes positioned above the recovery flotation. Another is sometimes positioned below the top flotation as a backup to the first swivel.
Note: this is still a point of argument for the "experts".

14) In general, less than 1 out of 100 experiments fail and flood. To account for possible flooding of some instrument casings, additional buoyancy added to the recovery flotation is between 100 and 150 lbs.

15) Factor of safety for wire rope: to determine a reasonable working load is a factor of five (5) (i.e., 1/5 of the breaking strength).

16) Factor of safety for Kevlar rope:

3 for launch transient;

5 for other than launch.

17) Factor of safety for nylon rope: 5.

18) Factor of safety for chain and other equipment shackles, links, etc.: 2.

19) Three basic configurations in the positioning of flotation are used in a mooring system. I) One or two large buoys at the top of the mooring, depending upon the currents, and glass balls as backup flotation. II) Similar to "1" but using one group of glass balls as primary buoyancy, and another as backup buoyancy. III) Glass balls spread throughout the mooring system with weak currents or nonacoustic arrays, and fewer glass balls as backup flotation.

19-A) In classification III the minimum number of glass balls in a cluster is generally two (2) to four (4). Individually spaced glass balls result in tangling on recovery [Berteaux & Heinmiller, 1973].

20) Seven basic types of seafloor materials are encountered in anchoring:

1) sand or gravel

2) mud or soft clay

3) stiff clay

4) very stiff clay or glacial till

5) soft rock or coral

6) hard, monolithic rock

7) boulders

A deployment site survey of the seafloor materials, thickness and variability, soil cohesion estimates, friction angle, and scour potential is required [Albertsen & Beard, 1982]. Friction coefficients for various seafloor materials are found in Table 2 [from Skop, in review].

21) Maximum topography slope for a deadweight anchor is 10 degrees. Beyond 10 degrees a pile or direct embedment anchor must be used.

22) Concerning top mooring retrieval floats, two or three glass balls above the primary floatation allow for easy retrieval of the mooring line. These floats are connected to the primary flotation by 15 meters of buoyant polypropylene rope for easy grappling. These retrieval floats are also used to position recovery aid equipment (flashing lights, transponders, etc.).

23) Length of primary and backup buoyancy chain for glass balls in meters [see Figure 14].

$$\text{Length} = ((1.43 * N) + 1)$$

where N = number of primary flotation 17" diameter glass balls.

24) There are two methods of incorporating a second (backup) release in the mooring design: series and

parallel [see Figure 15]. Series puts one release above the other, each taking the total force of the line at that position. Parallel has the two releases at the same depth with 50 percent of the forces passing through each one of them.

Problems of series usage: In this configuration, if the first release fails to fire at recovery then the second release is fired thereby losing the first release. Another problem is in the area of human error where a technician may activate the wrong release thus causing the loss of an expensive piece of equipment needlessly.

Problems of parallel usage: In this configuration either release can be fired, so firing the wrong release is impossible. But in contrast, these releases allow for less tension on the line since the forces on the line pass through the release itself.

25) Standard lengths for ropes and cables are in quantities of 500 meters. This is due to the standard size roll which is most easily deployable.

26) Instrument constraint : current meters have a maximum angle of 15° for operation.

27) When using acoustic arrays it is standard to have all the acquired data to be relayed to a recorder of some type. It is the capacity of the recorders which dictates the quantity of hydrophones or other acoustic equipment which can be used (ie. a 28 channel recorder

can only handle just so many hydrophones or Difars due to the number of twisted paired wires in the E/M cable and the number of channels in the recorder).

12.0 Top Mooring Recovery Configuration

Utilizing rules (13), (19.2 or 19.3), (22) and (23) we can standardize the upper configuration of the mooring [see Figure 16]. With rules (1), (13), (19.1) the configuration would be as in Figure 17.

13.0 Bottom Mooring Configuration

Utilizing rules (1), (2), (3), (4), (7), (13), (23) and (24) we can standardize the configuration of the bottom portion of the mooring [see Figure 18]. If we have instruments very close to the bottom or in shallow depths then rule (7) is eliminated and rule (4) can be reduced or eliminated as seen in Figure 19.

14.0 Numerical Description

Numerical routines external and internal to the expert system are used to perform the "number crunching" necessary to analyze a design. The following parameters analyzed are: Launch transients, elongation and the elastic properties of the wire rope and synthetic rope, behavior of mooring ropes, adjustment of the component lengths, and back-up recovery buoyancy.

14.1 Launch Transients

The maximum loading on the system is at the time of

launch. The forces generated at the time of launch cause permanent elongation of the cables, and can cause failure at the weakest point of the mooring. The expert system assumes an anchor last deployment and analyzes the launch transients using techniques due to Heinmiller (1976). This free-fall anchor descent is calculated by the following equations [Moller, 1976]:

$$T_i = \sum_{1,i} W + V^2 \tfrac{1}{2} p \sum_{1,i} C_d A \qquad (1)$$

where

T_i = tension in component i in pounds

$\sum_{1,i} W$ = sum of the buoyancies of components 1 through i

V = terminal velocity of the anchor (ft/sec)

$\sum_{1,i} C_d A$ = sum of drag coefficients times effective area for components 1 through i

p = mass density, (2.0 slugs/ft^3)

The terminal velocity:

$$V^2 = \frac{W_a - W_t}{\tfrac{1}{2} p \left(\sum C_d A + C_d A_a\right)} \qquad (2)$$

where

W_a = weight of the anchor (pounds)

W_t = net buoyancy of the mooring components at the anchor

$\sum C_d A$ = sum of the drag coefficients times the effective area of all components.

$C_d A_a$ = drag coefficient times effective area of the anchor

14.2 Elongation and the Elastic Properties of Wire Rope and Synthetic Rope:

Oceanographic cables commonly used are classified into three categories: wire ropes, synthetic fiber ropes, and chain. Of these types only torque balanced wire rope, Kevlar rope, nylon rope and chain are now considered "state-of-the-art". The ropes must be designed to be nonrotational; i.e. strands rotating one way must be balanced against strands rotating the other way. For wire rope, various constructions achieve this nonrotational status (3x19, 8x19, 19x7). Some wire rope constructions to avoid are 6x19, 7x25, and 6x25. For the Kevlar ropes, the types used are also torque balanced (counter-helix/torque balanced Kevlar and parallel strand). Similar considerations are also taken for nylon ropes (braided or torque balanced standard lay ropes).

Synthetic and Wire Rope: [Figures 20-24].

The elongation of wire rope due to tensile loading, applies to a rope that already has a permanent "construction-set"; i.e. the rope has been loaded and unloaded to 50% of the breaking strength 2 to 3 times. This construction-set is due to the initial loadings permanently tightening a new cable. This pre-working construction-set is needed to control the accuracy of a cable length to be used as a mooring line. With the permanent construction-set, wire rope has practically no plastic deformation and is assumed negligible. The elastic ϵ_E elongation of the wire

rope is the strain from the instantaneous response to loading.

The elongation of synthetic line due to tensile loading is the sum of the permanent plus the elastic elongation. The permanent elongation or plastic deformation ϵ_p is the remaining deformation resulting from the highest experienced strain in the cable's load history. Elastic elongation ϵ_E (percent of measured length) is also the strain from the instantaneous response to loading.

Of the synthetic line used for this expert system (Kevlar 29, Kevlar 49, and nylon) only nylon has enough permanent elongation to be of significance. Kevlar 29 and Kevlar 49 will have only .06% creep after being loaded at 50% of break strength for 10,000 hours (1 year). This compares to .04% creep for a steel cable [Cortland Cable Company, 1983].

For nylon the elongation percent is found by the equation [Moller, 1976]:

$$\epsilon_T = \epsilon_p + \epsilon_E \tag{3}$$

$$\epsilon_T = \left(\frac{T_m}{C_p d'} \right)^{B_p} + \left(\frac{T_i}{C_e d'} \right)^{B_e} \tag{4}$$

For Steel Wire Rope and Kevlar (no permanent elongation) the equation is

$$\epsilon_T = \left(\frac{T_i}{C_e d'} \right)^{B_e} \tag{5}$$

where

ϵ_T = total strain or percent elongation

T_m = maximum tensile force in the history of the line (lbs)

T_i = instantaneous tension (lbs)

d = diameter of the line (inches)

C_p = linear coefficient (permanent)

B_p = exponential coefficient (permanent)

C_e = linear coefficient (elastic)

B_e = exponential coefficient (elastic)

The coefficients A_p, B_p, A_e, and B_e (stretch characteristics constants of the rope) [see Tables 3 & 4] were obtained from the best fit obtained from stress-strain curves for the material. The ultimate elongation for nylon is in the order of 25 to 35 percent.

The equation can be used for some other synthetic lines such as Dacron since it is a standard equation for many types of synthetic ropes which utilizes the manufacturers' technique of loading the line to a tension in pounds to $200d^2$, where 'd' is the nominal diameter of the line in inches.

The above equations are derived from the expression [Wilson, 1967, November]:

$$\frac{T}{d^2} = C_e \left(\frac{L-L_o}{L_o}\right)^B$$

T = tension (pounds)

d = diameter of the line (inches)

L = stretched length of line

L_o = slack length of line

C_e = linear coefficient of elongation

B = exponential coefficient of elongation

The ultimate breaking strength (UBS) and the weight per unit length of the cable are approximately proportional to the diameter squared [Wilson, 1967].

$$UBS = C_b\, d^2 \tag{6}$$

$$w = C_w\, d^2 \tag{7}$$

where C_b and C_w are constants of proportionality of the cable material and construction [see Table 3], but these are needed only when the manufacturers' information is not available. The ultimate breaking strength of nylon should be reduced by 15 percent since nylon loses approximately 10 to 15% of its strength when wet.

A comparison of the different rope characteristics can be found in Table 5.

14.3 Behavior of Mooring Ropes:

Equations of Equilibrium and Hydrodynamic Loads

The static configuration of a subsurface single point mooring system is generated by various static forces: mooring line tension, gravitational forces, and hydrodynamic drag forces induced by constant or slowly varying currents. These currents are known to vary over the length of the mooring in both direction and speed and are obtained from profiles supplied by the scientist or generated by a "canned" algorithm. The velocity at any given point is derived from a linear interpolation of the profile data points [see Figure 25]. The forces, for the application at hand, are maximum in two-dimensional space due to the assumption of co-planarity conditions between cable and

current. The forces on the cable and a segment are shown in Figure 26A and 26B.

With respect to the X and Z Cartesian coordinate system (Y not applied due to co-planarity), the position vector of a point along a cable is $\mathbf{P} = P_X\hat{i} + P_Z\hat{k}$ ($\hat{i}$ and $\hat{k}$ are unit vectors along X and Z). To distinguish the particular location along the "cable to which **P** refers, the unstressed arc length s is used with s increasing from zero at the anchor to L, the total unstressed length of cable involved" [Skop, in review].

The static equilibrium state of a cable segment under an external load **f** (per unit of unstressed length) is

$$d(T\,\hat{\tau})/ds + \mathbf{f} = 0 \qquad (8)$$

where, T = Tension in the cable

$$\hat{\tau} = 1/(1+\epsilon)\ d\mathbf{P}/ds \qquad \text{unit tangent vector to the cable} \qquad (9)$$

The external force $\mathbf{f}=\mathbf{f}_W+\mathbf{f}_h$ consisting of $\mathbf{f}_W$ and $\mathbf{f}_h$ is made up of the hydrostatic and hydrodynamic loads. The hydrostatic load is

$$\mathbf{f}_W = -w\hat{k} \qquad (10)$$

where, w = cable weight per unit length in water

Hydrodynamic load consists of two components: normal drag ($\mathbf{f}_{hN}$) and tangential drag ($\mathbf{f}_{hT}$). Normal drag is dominant in mooring line applications due to the magnitude differences between the coefficients C_D (normal drag coefficient) and C_T (tangential drag coefficient) [see Figure 27] and is given by the expression:

$$\mathbf{f}_h = \mathbf{f}_{hN} + \mathbf{f}_{hT} \tag{11}$$

$$\mathbf{f}_{hN} = 1/2\ (1+\epsilon)\ \rho\ d \left[\alpha\ C_D\ |\mathbf{V}_N|\mathbf{V}_N \right] \text{ lbs/ft} \tag{12}$$

where,

$\mathbf{f}_{hN}$ = Normal drag, lbs/ft.

ϵ = Strain [see Section 14.2]

ρ = Fluid density, lbs/ft3

C_D = Normal drag coefficient

d = Diameter of cable, ft.

$\mathbf{V}_N = \mathbf{V} - (\mathbf{V}\cdot\hat{\tau})\hat{\tau}$ Velocity normal to the cable, ft/sec

α = Drag amplification factor [see Table 1]

Tangential drag, while much smaller than the normal drag, can be important when analyzing very long cable moorings.

$$\mathbf{f}_{hT} = 1/2\ (1+\epsilon)\ \rho\ d \left[\pi\ C_T\ |\mathbf{V}_t|\mathbf{V}_t \right] \text{ lbs/ft} \tag{13}$$

where,

$\mathbf{f}_{hT}$ = Tangential drag, lbs/ft.

C_T = Tangential drag coefficient

$\mathbf{V}_t = (\mathbf{V}\cdot\hat{\tau})\hat{\tau}$ Velocity of flow tangential to the cable, ft/sec.

Suggested values, due to orders of magnitude, of normal and tangential coefficients for flow regions below the critical Reynolds number are C_D = 1.2, C_T = 0.0. The normal drag coefficient for strut fairings with delrin ring gaps is C_D = 0.17 [Wingham, 1983] (note, this is taken into account

in the drag amplification factor α). When incorporating the tangential coefficient for long cable moorings a value of $C_T = 0.015$ is recommended.

For a single point subsurface mooring the load is known as a function of the arc length s. When the resultant force vector

$$\mathbf{R} = T\,\hat{\tau} \qquad (14)$$

is inserted into equation (8), then

$$\mathbf{R}(s) = \mathbf{R}_L - \int_L^s \mathbf{f}(\delta)\, d\delta \qquad (15)$$

where. $\mathbf{R}_L$ = Hydrodynamic load on the subsurface buoy supporting the moor

The Tension from equations (14) and (4) is given by the equation:

$$T = \mathrm{SQRT}(\mathbf{R}\cdot\mathbf{R}) \qquad (16)$$

We now obtain the position vector of the mooring segment:

$$\mathbf{P}(s) = \mathbf{P}_O + \int_0^s [1+\epsilon(\delta)]\, \mathbf{R}(\delta)/T(\delta)\, d\delta \qquad (17)$$

where, $\mathbf{P}_O$ = position vector of the anchor

These equations are classical expressions for the tension and the configuration of flexible cable in two-dimensional flow. A flow chart of these routines for obtaining the static solution iteratively is given in Figure 28 [from Skop, in review]. The DESADE computer code [Skop & Mark, 1973] utilizes these routines and, Consequently a

version of this computer program is accessed for analysis.

14.4 Adjustment of the Component Lengths:

Adjusting mooring lines is necessary when depth critical experiments are involved. The mooring designer will typically spend much time on this aspect. Once determining the mooring configuration, the expert system will compare this information with that of the objective depths. If an inconsistency in the two is found, adjustments are made and the new configuration recomputed. The mooring adjustment is accomplished by analyzing the lowest instrument and working upward until all instruments are satisfied. Equations of length adjustments are:

$$L_c = L + (D_c - D_d) \tag{18}$$

where L_c = corrected length of the cable

L = original length of the cable

D_c = calculated depth

D_d = desired depth

14.5 Back-up Recovery Buoyancy:

Back-up recovery buoyancy is necessary when there is a mooring failure. With this back-up system all instruments below the failed point can be recovered. This back-up buoyancy, consisting of glass balls, is "calculated by adding the weights of all components except buoy and anchor, adding a reserve buoyancy and dividing by the effective individual buoyancy of spheres used" [Berteaux & Heinmiller, 1973]. Back-up buoyancy is used on arrays that only have

one or two large spheres or glass ball clumps as the main flotation. Arrays that have a series of floats/glass balls throughout the system do not need this backup system, since the backup flotation is included in the dispersement of the flotation. Equations to calculate the back-up buoyancy are:

$$R = Rt - \sum_{1,i-1} W \tag{19}$$

$$N = R \div IB \tag{20}$$

where R = the back-up buoyancy at each component i (lbs)

Rt = total reserve buoyancy of the mooring

$\sum_{1,i-1} W$ = sum of the buoyancies of all higher components

IB = Buoyancy of an individual glass ball

N = Number of glass balls required

15.0 Corrosion:

Corrosion of the steel cable and various steel components in the mooring system is a prominent reason for failure in extended deployment or in deployments in regions of high current. It has been found in experiments in the Straits of Gibraltar that corrosion speed is in the order of three times the velocity [H. O. Berteaux, personal communication, February 17-19, 1987]. The reasoning behind the greater corrosion rate in higher velocity regions is due to the greater amounts of oxygen passing by the cables. The higher velocities also facilitate in the removal of rust/corrosion areas allowing new metal to be exposed, quickening the corrosion rate. To compensate for the corrosion rate of the steel cable various methods are used:

- ZINC COATING (Galvanizing)
  (good for 2 months calm water)
- PLASTIC JACKETED
  (extends life in the order of months to years)
- LUBRICANTS
  (not recommended - they have very short life)
- STAINLESS STEEL (not recommended - very short life)

OTHER EQUIPMENT - have no recommended coatings.

16.0 Data Bases:

Access to data bases is one of the most important features necessary in an expert system. Data bases allow information to be broken down and utilized in a reasonable manner rather than in one gigantic bundle. Updating the data bases which are pertinent to the user allows new information to be added to the program thereby keeping the program up to date in technology.

Data Bases accessed by the user:

Ropes & Chain:

Wire Rope   Kevlar Rope   Nylon Rope   Chain

Flotation:

Steel and Aluminum floats   Glass Balls   Syntactic floats

Instruments:

Current Meters	Hydrophones
Acoustic Releases	Inclinometers
Tension Recorders	Depth Recorders
Transponders	Acoustic Recorders

Odd types/unspecified/unique instruments

Equipment:

Shackles Pear-sling-links

Using dBaseIII format the following fields and characteristics would be used for the above data bases.

Instruments:

Field name		Type	Width	Dec
Type	:	Character	32	
Length (meters)	:	Numeric	5	2
Area (meters²)	:	Numeric	8	5
Weight (air)(lbs)	:	Numeric	6	2
Weight(water)(lbs)	:	Numeric	6	2
Maximum depth (m)	:	Numeric	4	0
Drag Coefficient	:	Numeric	5	3
Maximum Tension allowed across instrument	:	Numeric	6	0
Cost ($)	:	Numeric	7	2

Wire, Kevlar & nylon rope:

Field name		Type	Width	Dec
Size	:	Character	6	
Construction	:	Character	14	
Weight (air) (lbs/ft)	:	Numeric	5	4
Weight (water)(lbs/ft)	:	Numeric	7	3
Rated Breaking Strength(lbs)		Numeric	6	0
Plastic Coefficient	:	Numeric	6	0
Plastic Exponent	:	Numeric	4	3
Elastic Coefficient	:	Numeric	6	0

Elastic Exponent	:	Numeric	4	3
Drag Coefficient	:	Numeric	5	3
Area (meters^2)	:	Numeric	9	8
Cost ($)	:	Numeric	7	2

Chain:

Field name		Type	Width	Dec
Size	:	Character	6	
Construction	:	Character	14	
Weight (air)(lbs/ft)	:	Numeric	5	4
Weight (water)(lbs/ft)	:	Numeric	7	3
Rated Breaking Strength(lbs)		Numeric	6	0
Drag Coefficient	:	Numeric	5	3
Area (meters^2)	:	Numeric	9	8
Cost ($)	:	Numeric	7	2

Flotation:

Field name		Type	Width	Dec
Size	:	Character	6	
Construction	:	Character	14	
Weight (air)(lbs)	:	Numeric	5	4
Buoyancy (Weight in water) (lbs)	:	Numeric	4	0
Area	:	Numeric	7	5
Depth Rating	:	Numeric	4	0
Drag Coefficient	:	Numeric	5	3
Cost ($)	:	Numeric	7	2

Shackles:

Field name		Type	Width	Dec
Size	:	Character	8	
Safe Working Load (lbs)		Numeric	8	2
Inside length	:	Numeric	7	5
Inside width	:	Numeric	7	5
Pin diameter	:	Numeric	7	5
Outside of eye diameter		Numeric	7	5
Weight (lbs)	:	Numeric	5	2
Cost ($)	:	Numeric	5	2

Sling Links:

Field name		Type	Width	Dec
Size	:	Character	8	
Inside length	:	Numeric	4	2
Inside width (small end)	:	Numeric	4	2
Inside width (large end)	:	Numeric	4	2
weight (lbs)	:	Numeric	4	2
Safe load single pull(lbs)	:	Numeric	6	0
Cost ($)	:	Numeric	5	2

17.0 Controlling the Buoy Motion:

Suppressing the motion of the mooring system is necessary when the experiments instruments involved have operational constraints which make it necessary for the instrument to reside within a certain depth or region. Two types of motion are encountered by the instrument: dip and excursion. Dip is the vertical rise and fall of an

instrument or buoy from the influence of the current on the cable system, and excursion is the horizontal motion.

Controlling dip also constrains the excursion. When the designer specifies the depth of an experiment he will also specify any constraints on the dip of the instrument (ie. +25m -0m). If there are constraints then the tension of the cables is adjusted so that dip and excursion are reduced to allowable limits. Starting from the instrument closest to the anchor and working upward, each instrument is checked for proper positioning. To verify the instrument positioning, the instrument is located at the extreme apex of the region and then observed with the applied forces to fall within the region. If the instrument falls outside the region then the buoy must be enlarged and the cable size may need to be increased to a point that the tension in the line satisfies the constraints.

The dip and the excursion motion restrictions set by the scientists are noted to be an area of controversy. Many times the restrictions set forth by the scientist are outside physical reality. One cannot design a mooring 5000 meters in length and be able to keep a scope of one meter!

Another aspect which is critical to some instruments is the maximum tilt angle. This is encountered in various current meters which have a maximum tilt angle of 15 degrees. The tilt angle is also adjusted by the tension in the cable.

The nominal depth position of an experiment is the

"Working" area of the experiment. For a current meter the working area is the rotor. For a pressure experiment it is where the sensors are.

18.0 Cost Analysis:

Once a design is determined feasible by the expert system, all equipment in the mooring array is checked in 1987 prices and a total cost report generated with the cost information available. If some items lack a cost then these prices are omitted and relayed to the user of their unavailability. Inquiring as to whether the prices are within a satisfactory range, and relating possible changes/tradeoffs that may reduce the cost, permits the user/designer to try other scenarios to obtain the cheapest and most reliable mooring possible.

19.0 Trade Offs:

Upon the realization by the expert system that a mooring design is not feasible, the development of the mooring design is immediately halted. Information and nature of the suspension of the design is relayed to the user. If recommendations are possible they are presented along with the reasoning behind each recommendation. If the "why" facility is a possible source of obtaining information on the problem, then this knowledge is supplied to the designer. The extent of the seriousness of design failure is also conveyed to the designer. This allows the designer to understand the problem completely, make the necessary

changes, and rerun with the new constraints.

20.0 Graphic Representation:

Two strategies are available in presenting graphically the output of a mooring design. The first strategy is through the use of a CAD package, the other is by designing an output package specifically for handling the specialized information.

Designing the output package is achieved through specific programming disciplines that permit graphic output. Once the method and language is selected, an algorithm for each of the 28 different mooring classifications is generated with variables allowing for instrument and depth information. Graphical representation of each instrument and various equipment is formulated and positioned.

Output machines such as eight pen plotters, laser printers and dot matrix printers have their own specific configuration and drivers. It is this specificity that causes the output algorithm to be machine specific.

Utilizing a CAD package is accomplished through the activation of any one of the various CAD design packages developed by an independent vendor. These packages do not allow for input into the design from an external ASCII text file, but require the user to enter the package and input the information to be designed and then plotted. The input of the information is facilitated by various menus that are developed specifically for the situation at hand. With the developed menus and the basic outlines of the 28 different

mooring classifications, the instruments and depths with any other information the designer/user desires can be incorporated into the design. A procedure outline supplied with the package on the CAD's operation, menu utilization, and what the user must know in order to output a correct design, is necessary to prevent confusion. If the basic CAD frames are set up in an adequate manner, then the user need only to follow basic commands and menu queries to make the necessary changes from the initial basic design file.

Of the two strategies the first's limitations of requiring the technical information on the various machines of the hundreds of plotters, printers, and output devices makes this strategy basically obsolete. The other strategy forces the user/designer to input/change information on technically drawn designs of the 28 classifications, which makes this method more prone to mistakes.

21.0 Output of Design: [Figure 29-34]

Presentation of all the necessary information the user requires to generate a usable design is done in standard format found in most company design departments. The user is also given an option on whether he wants the output presented in English, Metric units, or in standard format. Standard format mixes both English and Metric units in the presentation.

Necessary information to be presented:

Project title

Designer

Project number

Date developed

A - Complete parts list

B - List of parts from top to bottom of where each part is used as in the examples given. A note on the length of time for deployment should also be included.

C - A printed graphics output, if the designer has the machine capabilities. Most of (B) is in this graphics output. The size drawing will either be an "A" (8x11), "B" (11x17), or "C" (17x23) size drawing depending upon complexity.

D - Glossary - List of terms on the mooring design to eliminate confusion on the part of the designer.

E - Discussion of the limitations of the system along with any other pertinent information which may be needed.

F - Disclaimer against all liabilities concerning the system's use.

G - Estimated cost of each component and the final cost analysis.

22.0 Hardware required:

640 K RAM

A hard disk is recommended for satisfactory disk access speed.

Two floppy drives alone will work but the slowness of the disk access makes this combination impractical.

Clock speed of 8.77 or greater is recommended for reasonable response time in the design process. (IBM AT)

8087, 80287 or 80387 math coprocessor to reduce the calculation time of the technical mooring analysis.

Graphics Monitor (Color or MonoChrome) for previewing plots.

Plotter 2,4, or 8 pen.

Printer

23.0 Conclusion:

The implementation of an expert system for the design of single-point subsurface moorings is achievable with present computer technology. The methods and structure of these designs are well established allowing for immediate incorporation of this knowledge into an expert system for mooring design.

This report presents information, obtained from experts, literature, and other sources, needed to successfully implement a useable and reliable system. An Insight 2+ knowledge base for implementing a mooring expert system is given in appendix D. This knowledge base acts as the design engineer and selects the type of mooring and acts upon that information by activating various routines to create, evaluate, modify, adjust and present the design to the user/scientist. Aspects which need to be developed in future work on the expert system entail the programming of

the analytical sections of the knowledge base which does the structural analysis of the cable system input by the inference engine. The contents of these analytical programs are presented in the expert system flow chart [see appendix C]. These analytical programs along with the output algorithm contain the final aspects to implement a usable system. The only complications are in the output of the mooring design in graphic form since the graphics equipment to be used dictates the output algorithms.

24.0 References:

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Appendix A:

Table 1. Drag Amplification Factors for Bare Cable and for Common Strumming Suppression Devices [Every, King, and Weaver, 1982]

Suppression Device	Size	Factor α
Bare Cable	Horizontal Riser	2.00 1.50
Hair	6d long 0.5d spacing	1.00
Ribbon	4-6d long 1-2d wide 1-2d spacing	1.67
Fairings	Wrap-round Rigstream	0.13

Table 2. Friction Coefficients for Deadweight Anchors

	Friction Coefficient μ *		
Type Anchor	Sand	Mud or Soft Clay	Stiff Clay
Clump	0.98	0.60	0.84
Porcupine	0.98	0.70	0.98
Chain	0.98	0.90	1.25
Wire Rope	0.98	0.45	0.63

* Average values for design.
Actual values can vary by ± 25%

TABLE 3. Mechanical Characteristics of Wire and Chain

Material Construction	C_b (lb/in^2)	C_w (lb/in^2)	C_e (lb/in^2)	B_e
Extra Improved				
Plow Steel			7.9×10^6	
8x19	91,000	1.45	"	1
19x7	84,400	1.45	"	1
Improved				
Plow Steel			7.9×10^6	
3x19	100,600	*	"	1
8x19	79,200	1.45	"	1
19x7	76,600	1.45	"	1
Chain*	85,000	-	-	-

* For chain, the diameter d is the bar/wire diameter.

A reasonable value for C_w in cases where none are given or unable to be found are: Steel C_w= 1.23 (lb/in^2)
Chain C_w= 8.70 (lb/in^2)

TABLE 4. Mechanical Characteristics of Synthetic Fiber Ropes 1" Diameter rope. First Cycle Loading.

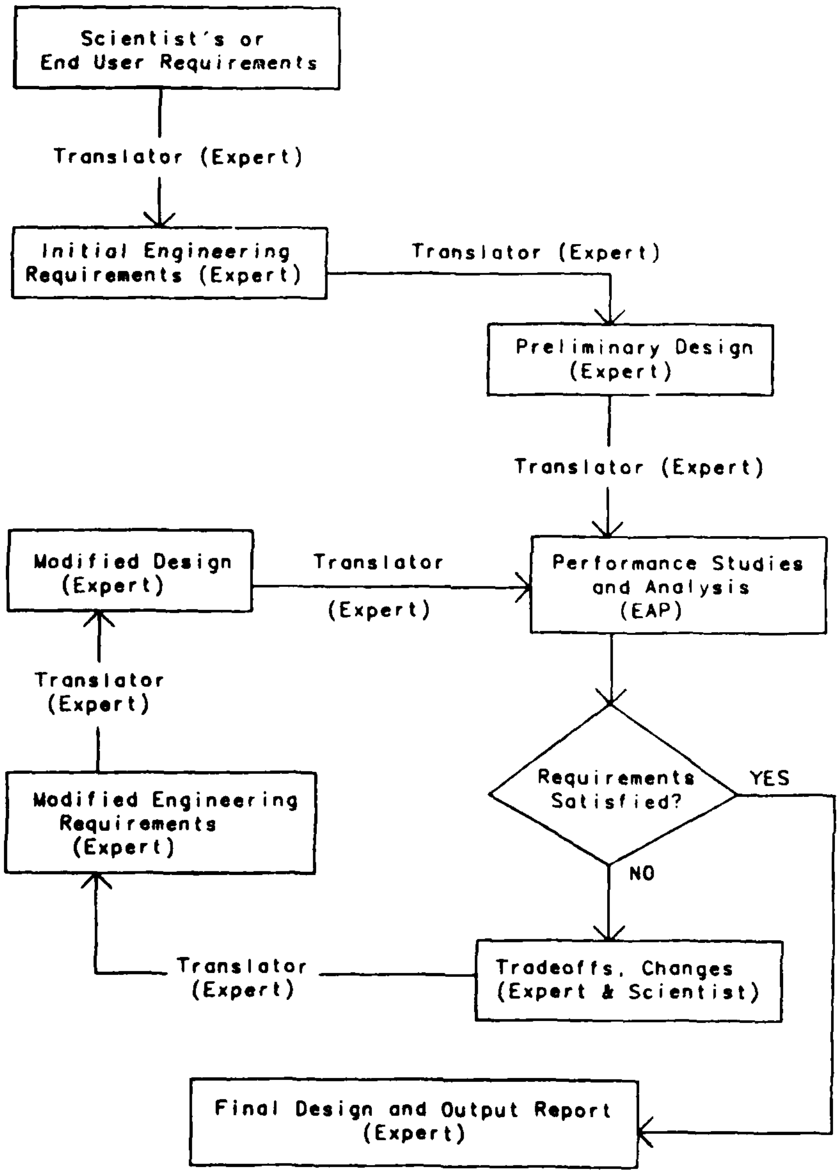
Material Construction	C_b (lb/in^2)	Ce (lb/in^2)	B_e
Nylon			
Non-parallel		C_p = 1.56×10^5 (lb/m^2)	Bp= 1.94
yarns	25,000	C_e = 1.3262×10^5 (lb/m^2)	Be= 1.87
KEVLAR 29			
Parallel yarns	84,000	2.8×10^6	1
Counter-Helix	90,000	2.8×10^6	1
JETSTRAN I-A	110,000	2.8×10^6	1
SPECTRA 900	119,000	2.9×10^6	1

Reasonable values for C_w in cases where information is not supplied by the manufacturer are:

Nylon C_w= 0.033 (lb/in^2)
Kevlar C_w= 0.090 (lb/in^2)

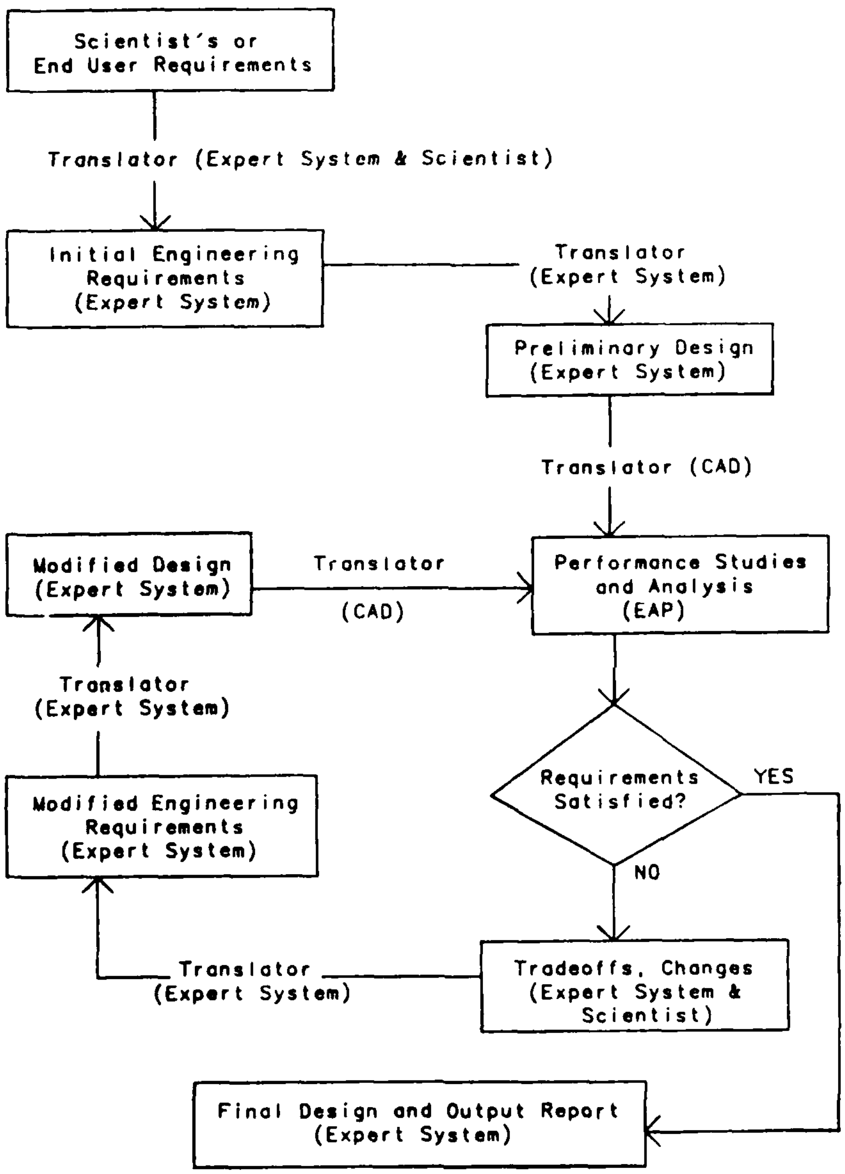
Table 5. Comparison of Nylon and Kevlar Characteristics with rope having Identical Breaking Strengths.

Material:	Diameter Ratio	Weight ratio per foot	Drag ratio per foot	Elongation at 20% of breaking
Improved Plow Steel	1.00	1.00	1.00	0.2%
Nylon	1.84	0.09	1.84	15.0%
Kevlar	1.01	.07	1.01	0.6%



EAP = Engineering Analysis Package

FIGURE 1: Traditional design engineering strategy flow chart.



CAD = Computer Aided Design Package
EAP = Engineering Analysis Package

FIGURE 2: Expert System/CAD design engineering strategy flow chart.

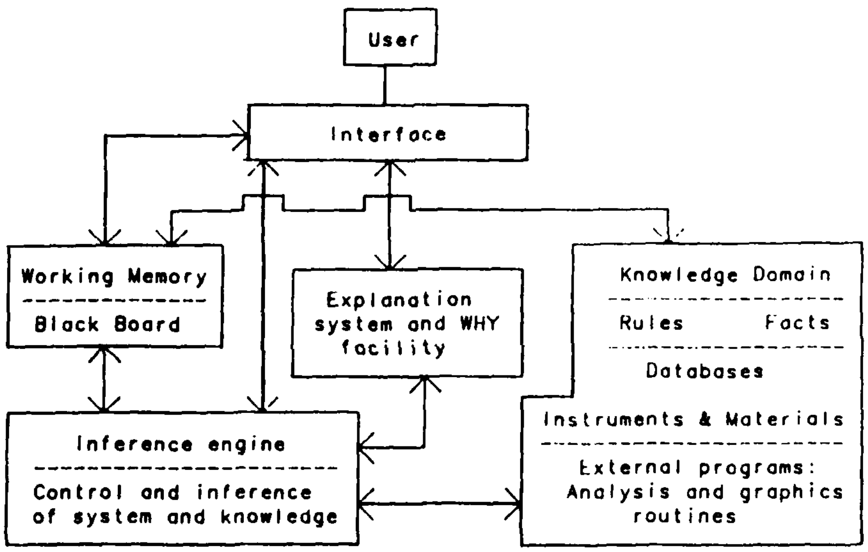
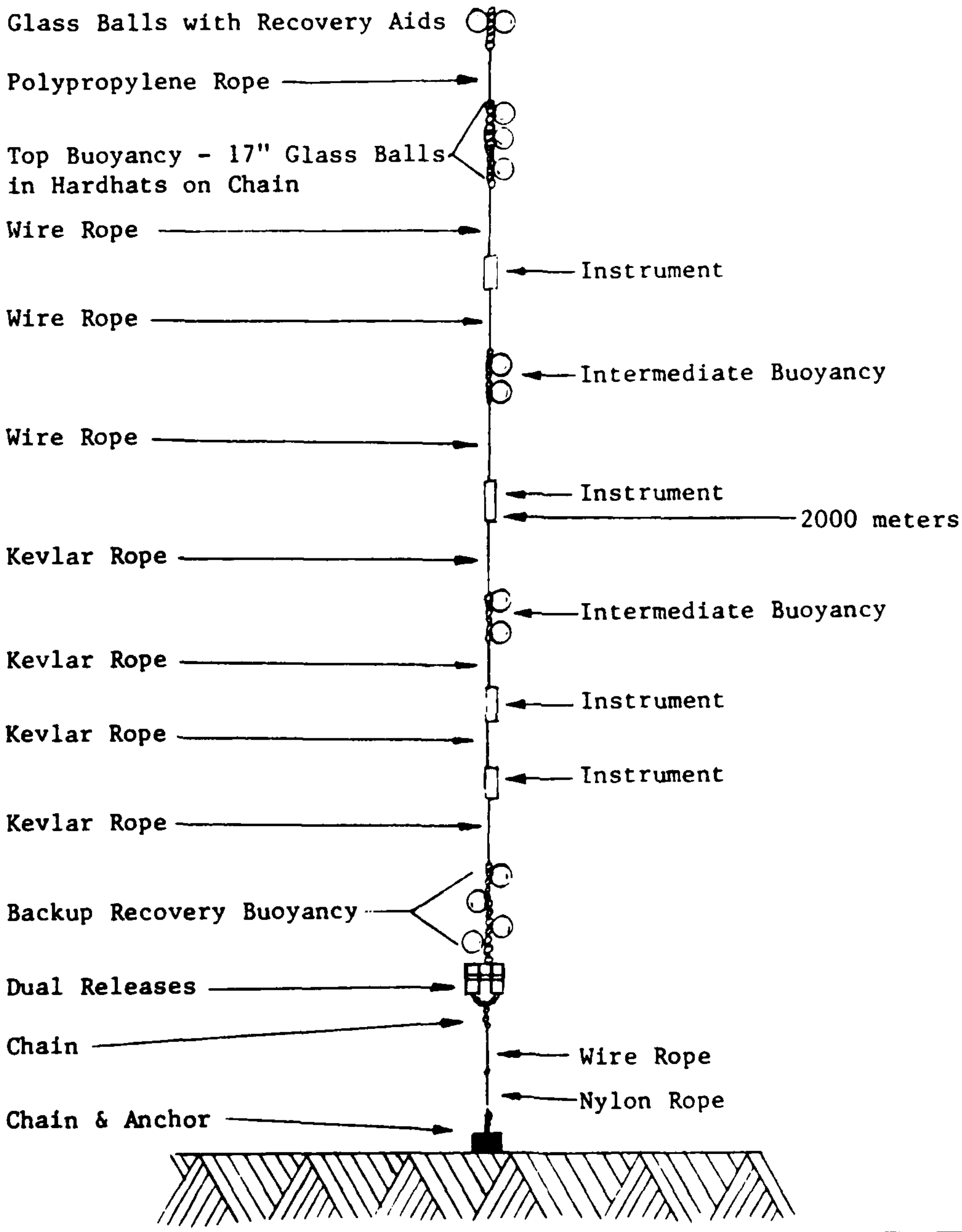


FIGURE 3: Conceptual design of a mooring expert system.



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CHECKED:	Typical NonAcoustic Subsurface Mooring with Buoyancy Section at Several Depths Figure 4		
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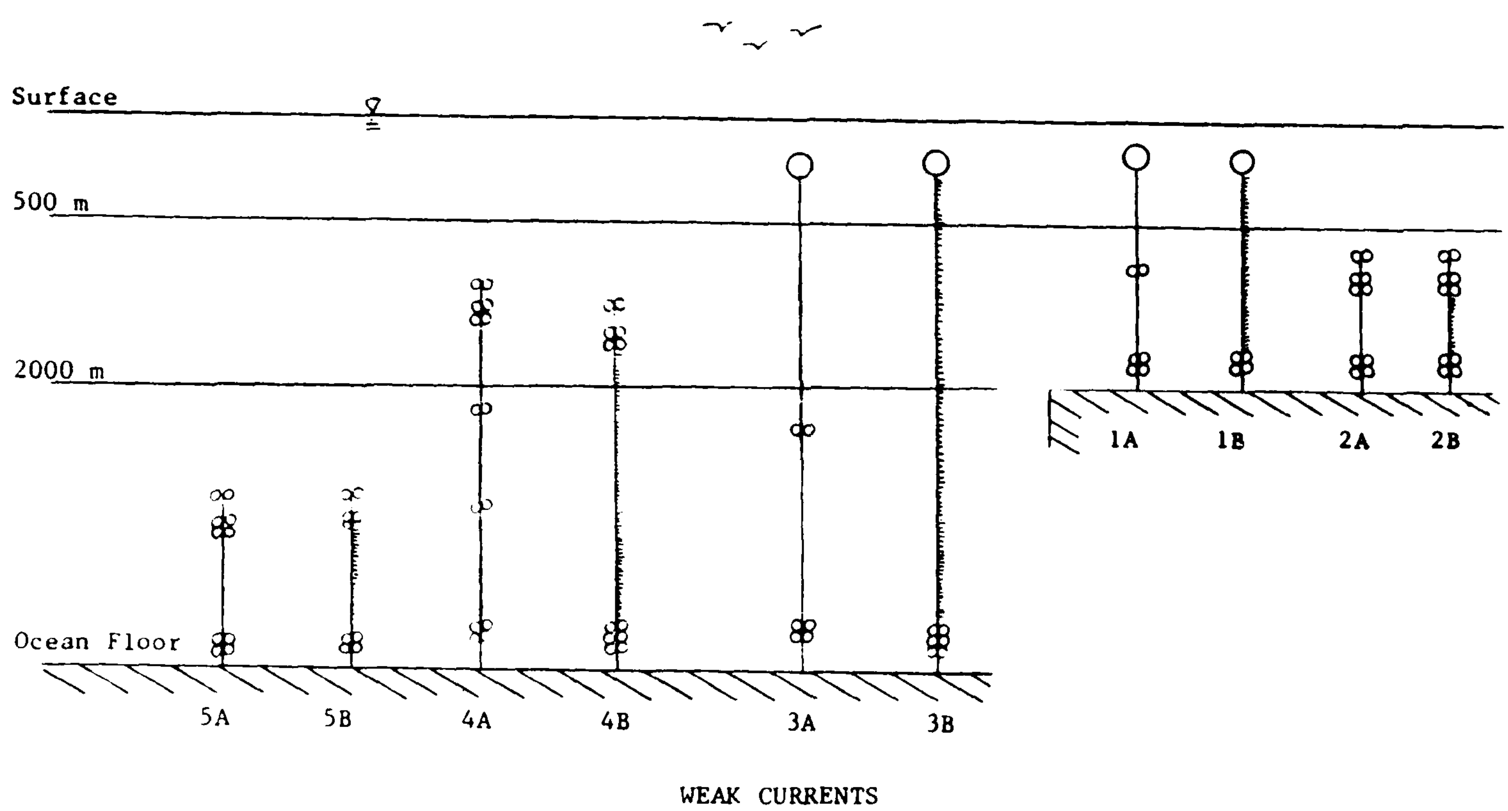


Figure 5: CLASSIFICATION 1 through 5 of ACOUSTIC AND NONACOUSTIC MOORING ARRAYS

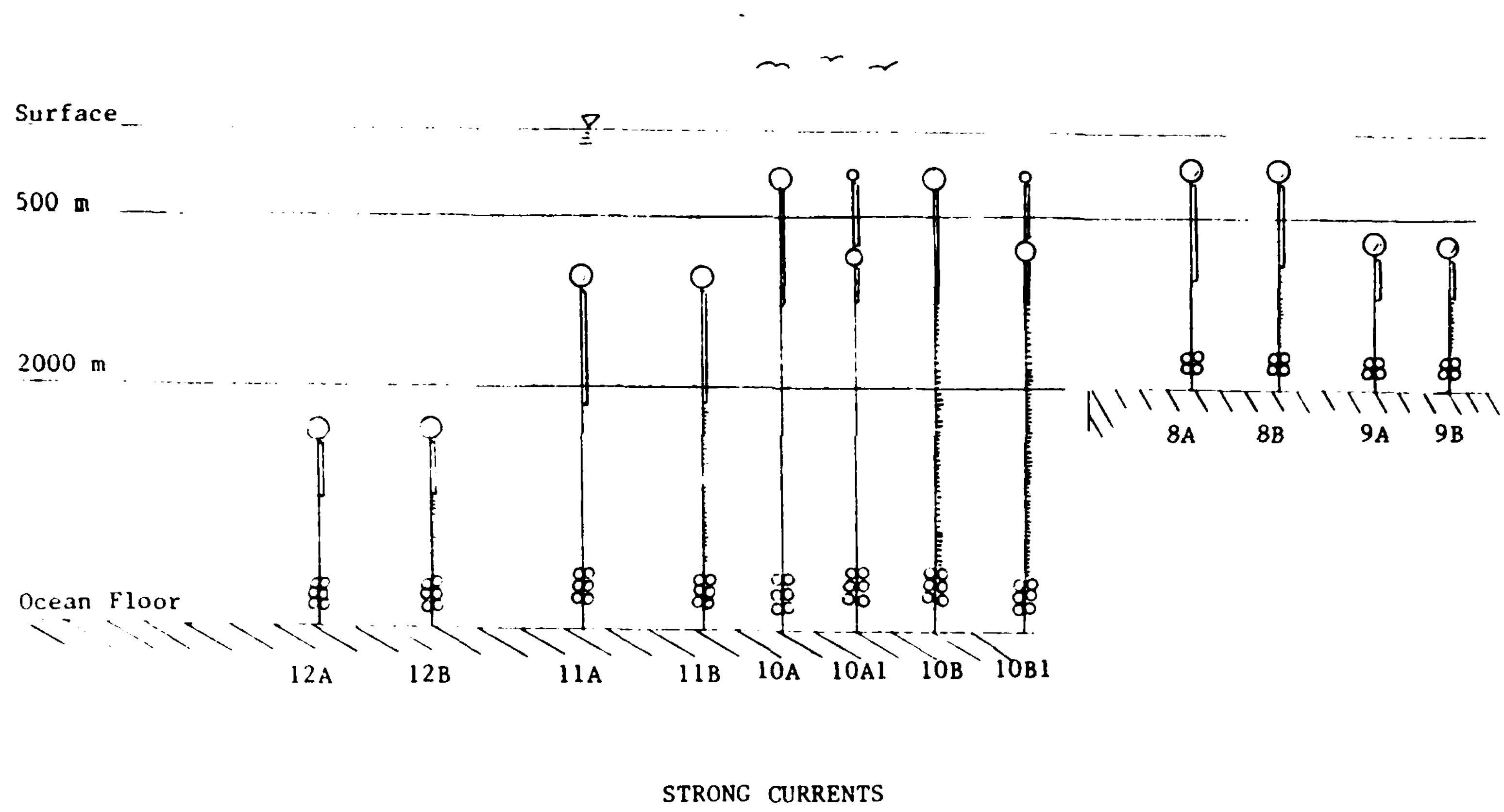


Figure 6: CLASSIFICATION 8 through 12 of ACOUSTIC AND NONACOUSTIC MOORING ARRAY

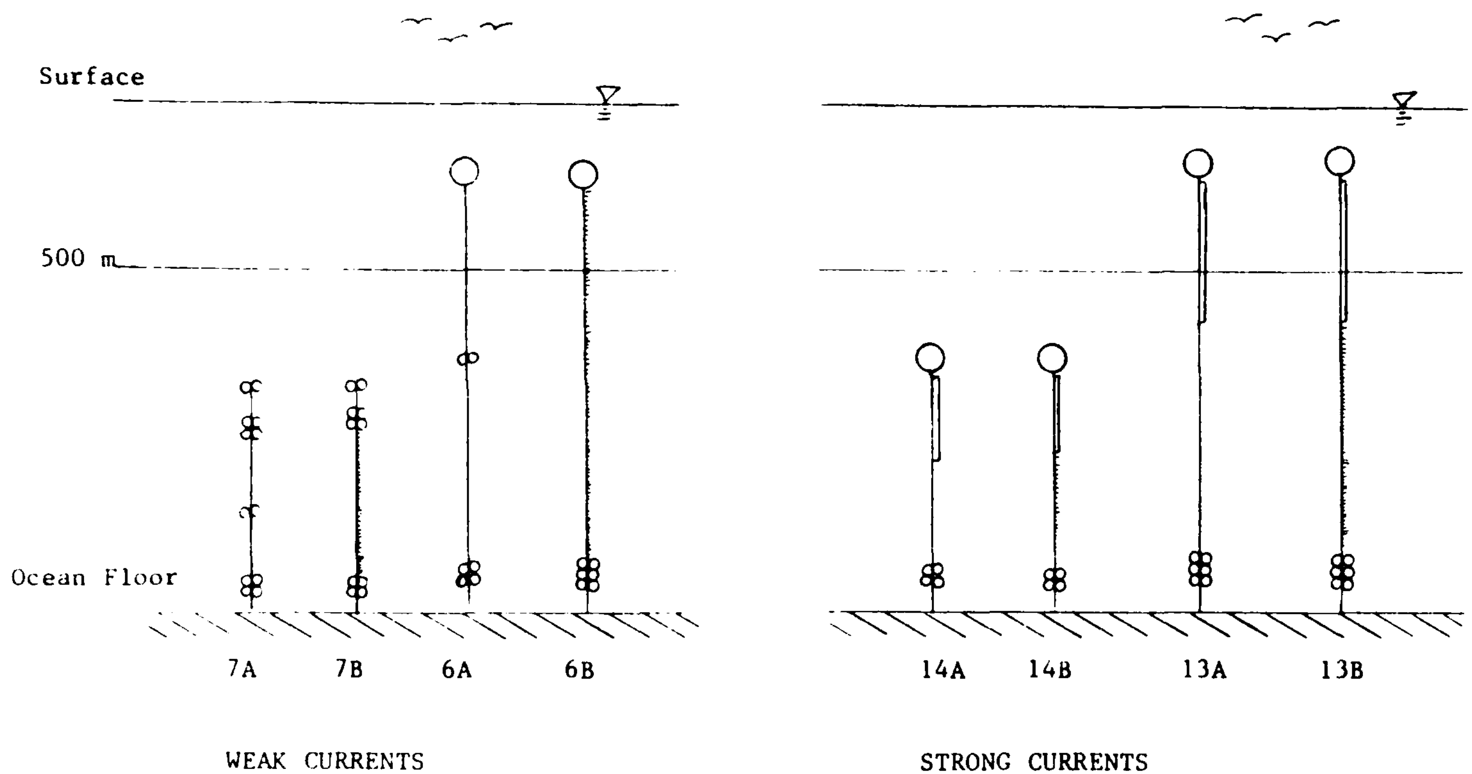


Figure 7: CLASSIFICATION 6,7; 13,14 of ACOUSTIC AND NONACOUSTIC MOORING ARRAYS

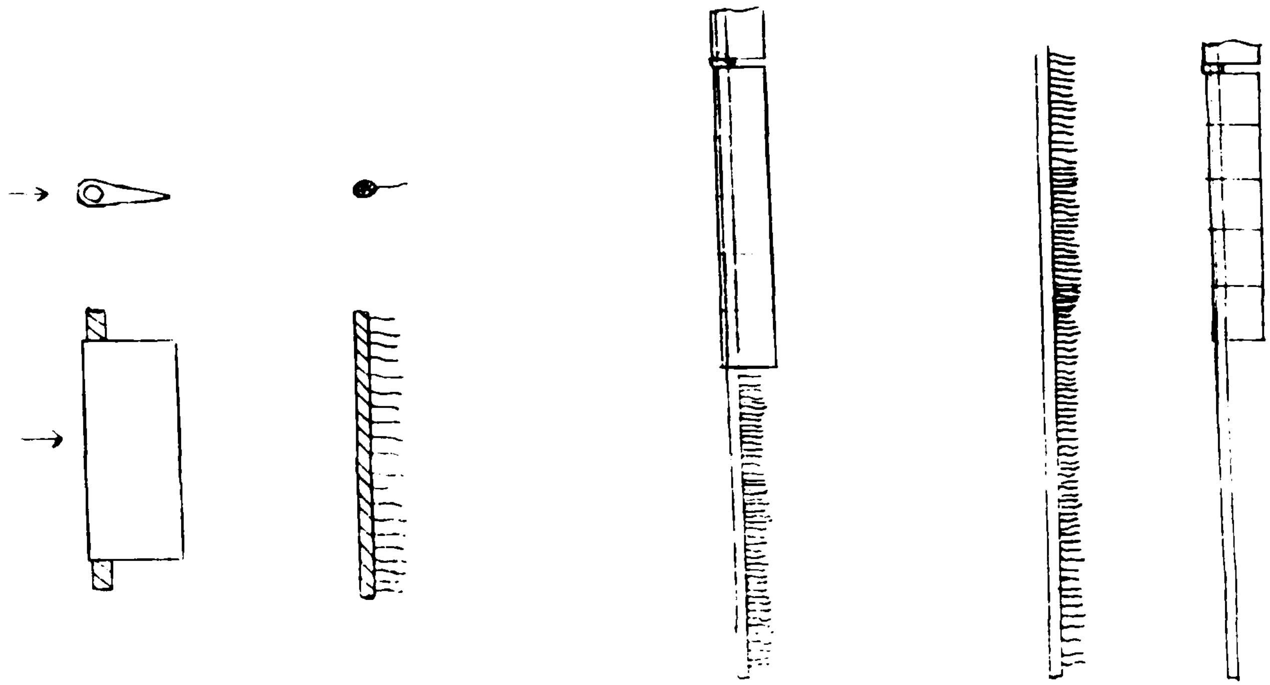


Figure 8: Schematic of Fairing Use and Design Configuration

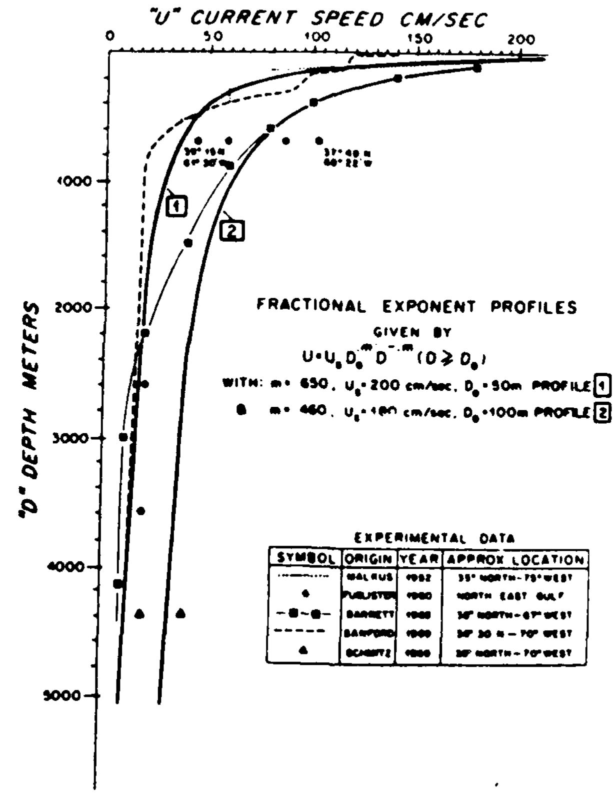


Figure 9: Gulf Stream Current Profiles
(Berteaux, 1970)

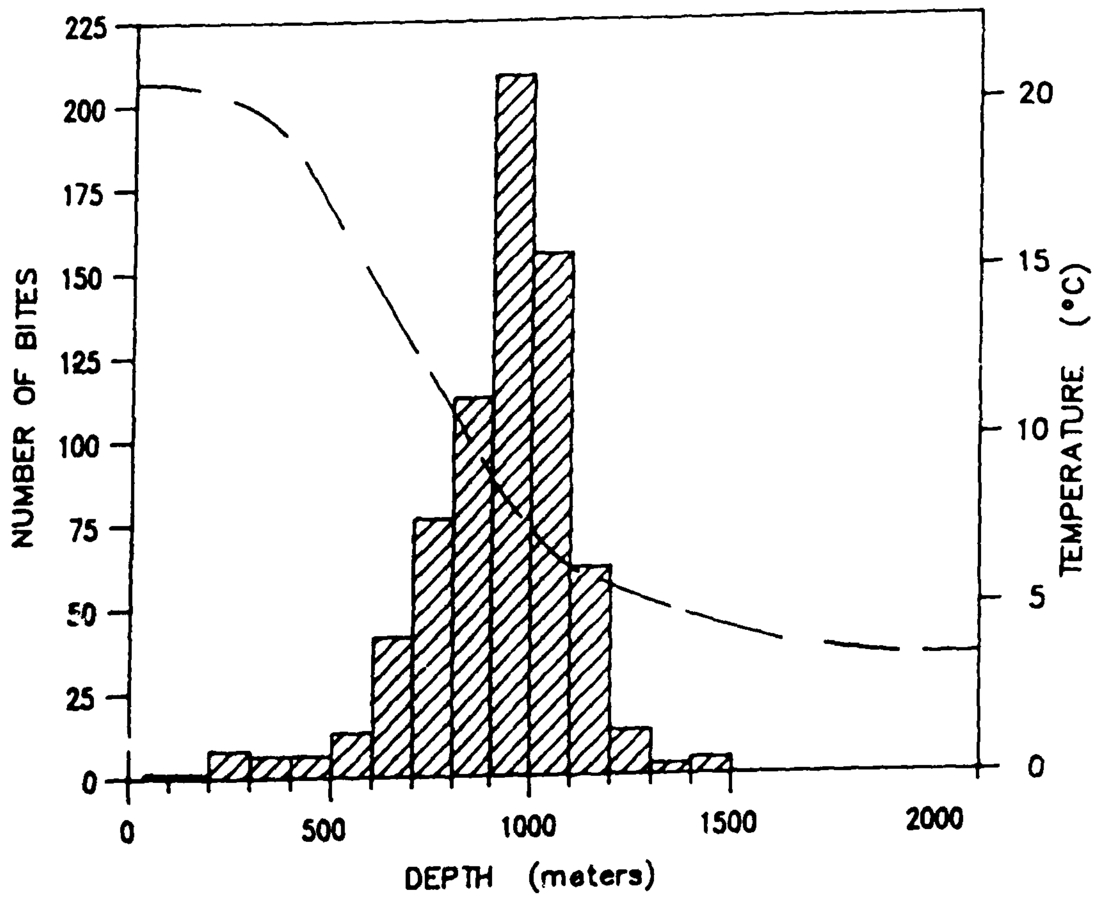


Figure 10: Frequency of Bites as a Function of Depth (Prindle and Walden, 1975) and Mean Thermal Structure (Fuglister, 1960)

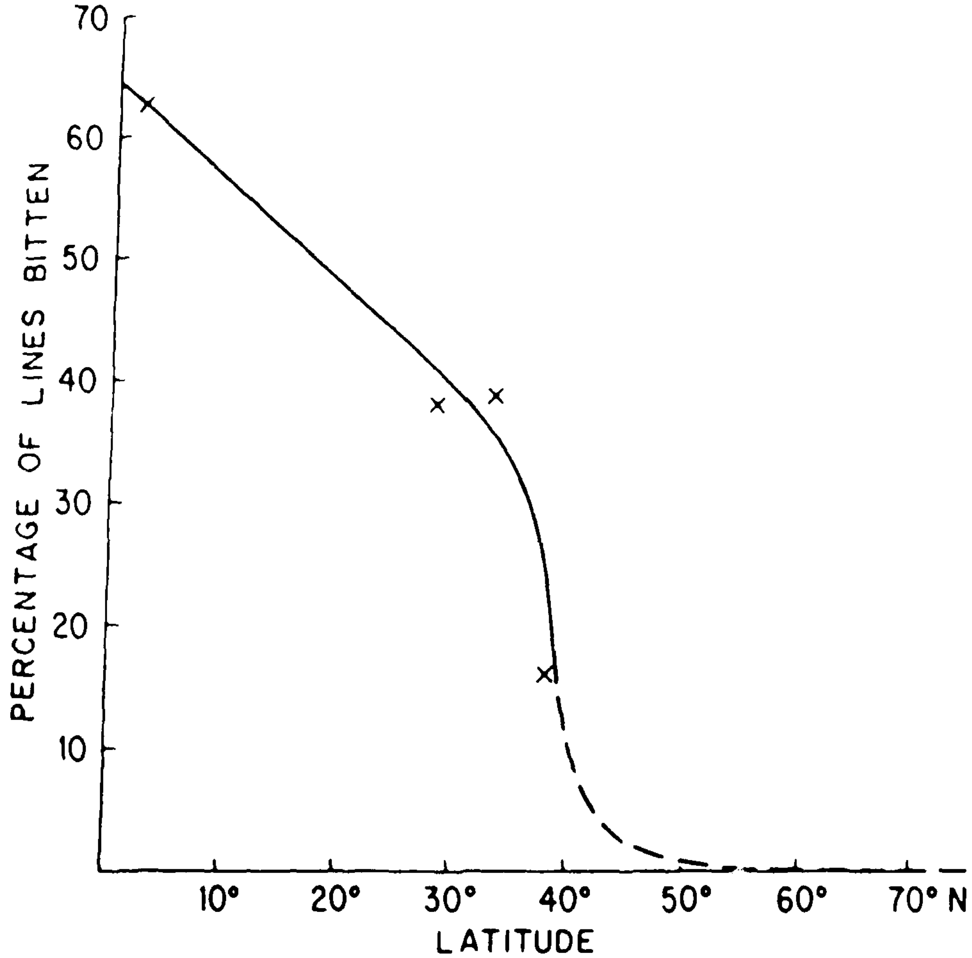


Figure 11: Percentage of Lines Bitten vs. Latitude
(Berteaux, 1987)

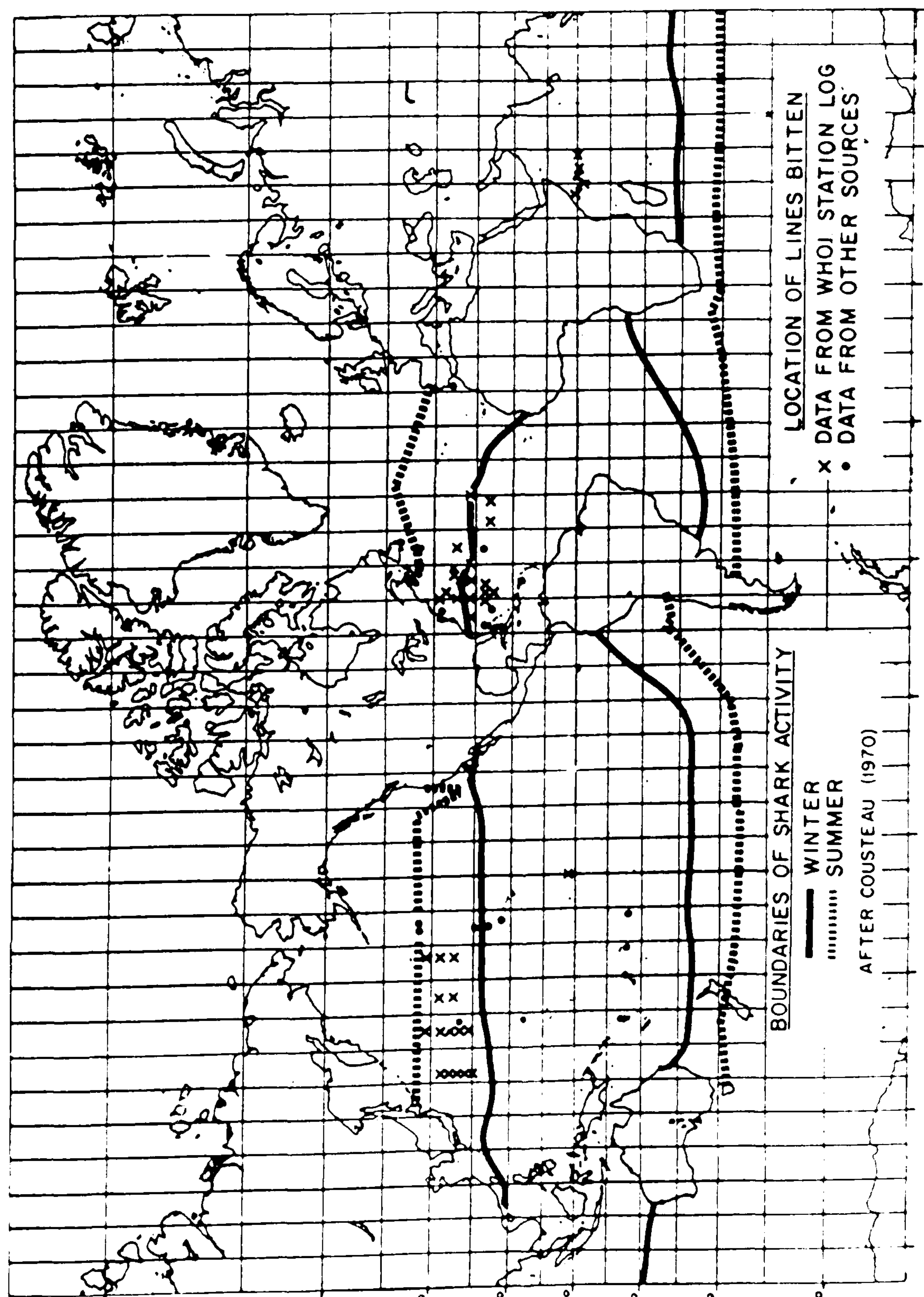


Figure 12: World geographic distribution of fishbite incidence. (Berteaux, 1987)

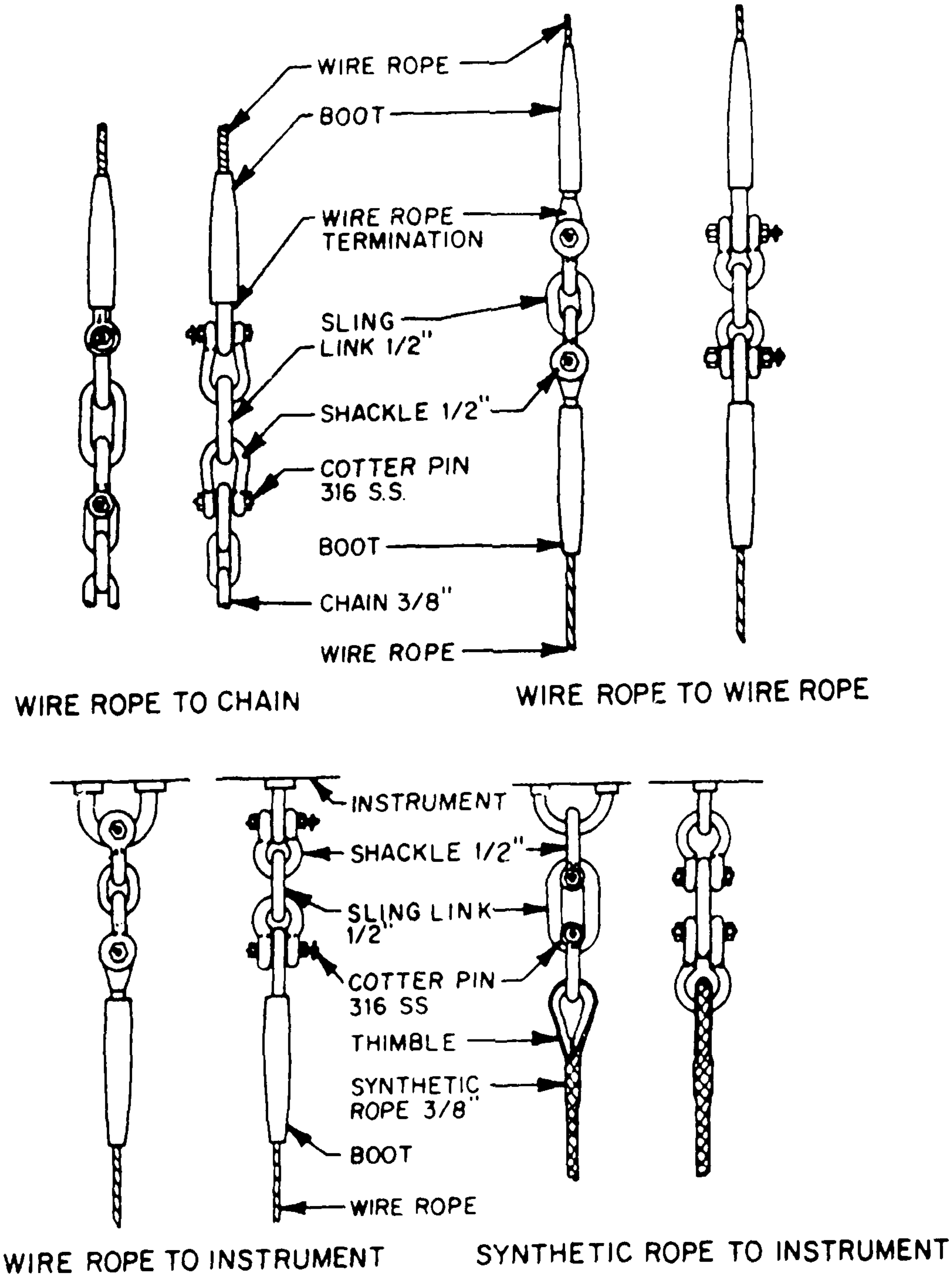
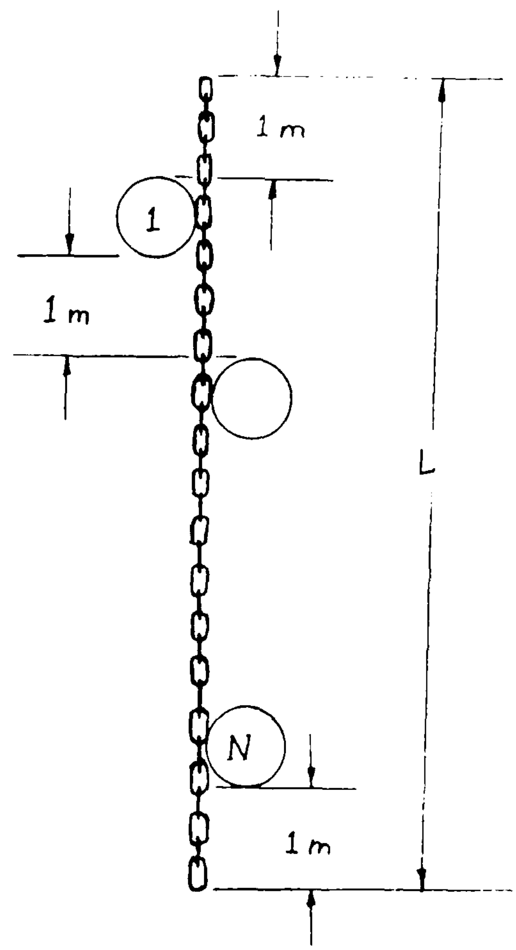


FIG. 13: TYPICAL HARDWARE INTERCONNECTIONS

(Heinmiller, 1976)



$$L = ((1.43 \times N) + 1)$$

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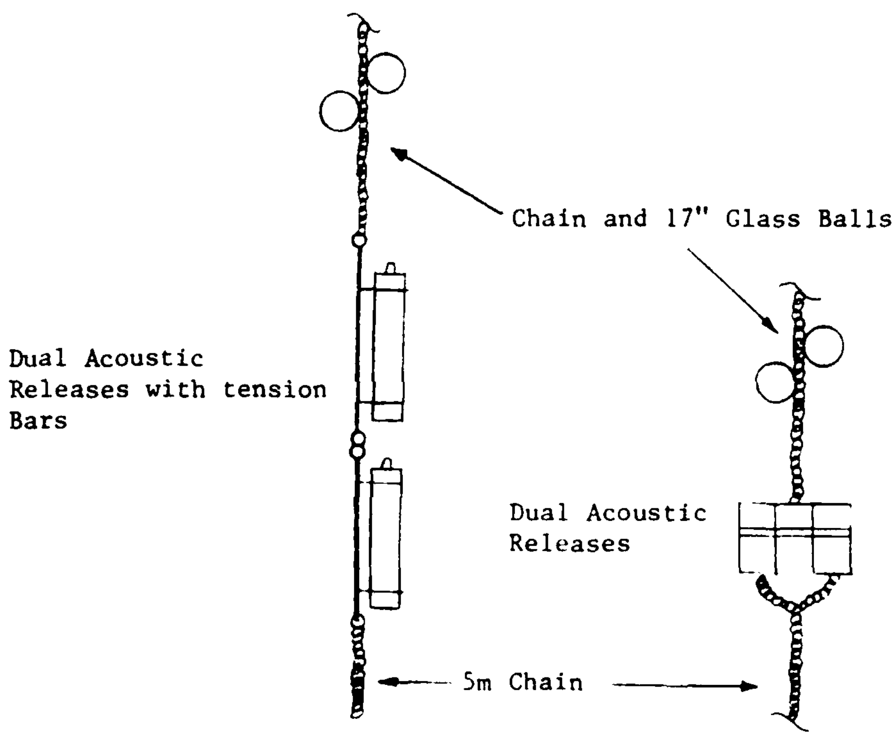

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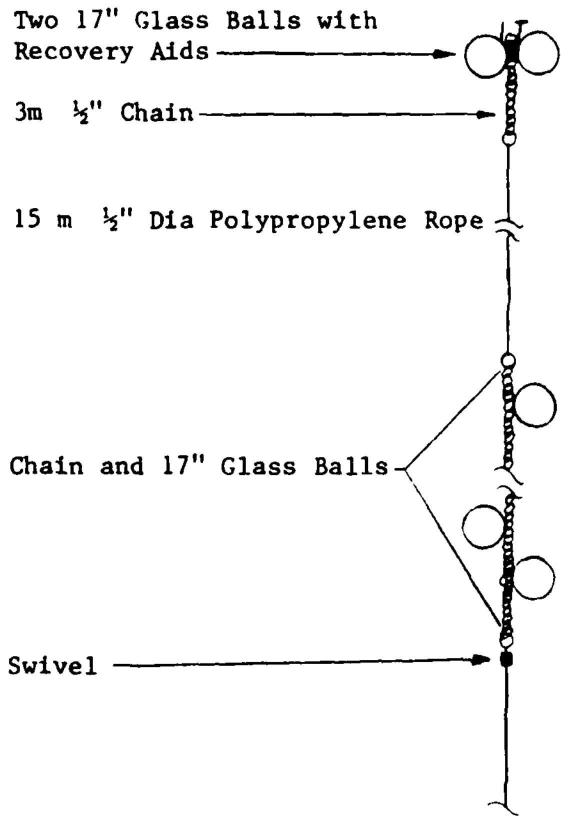

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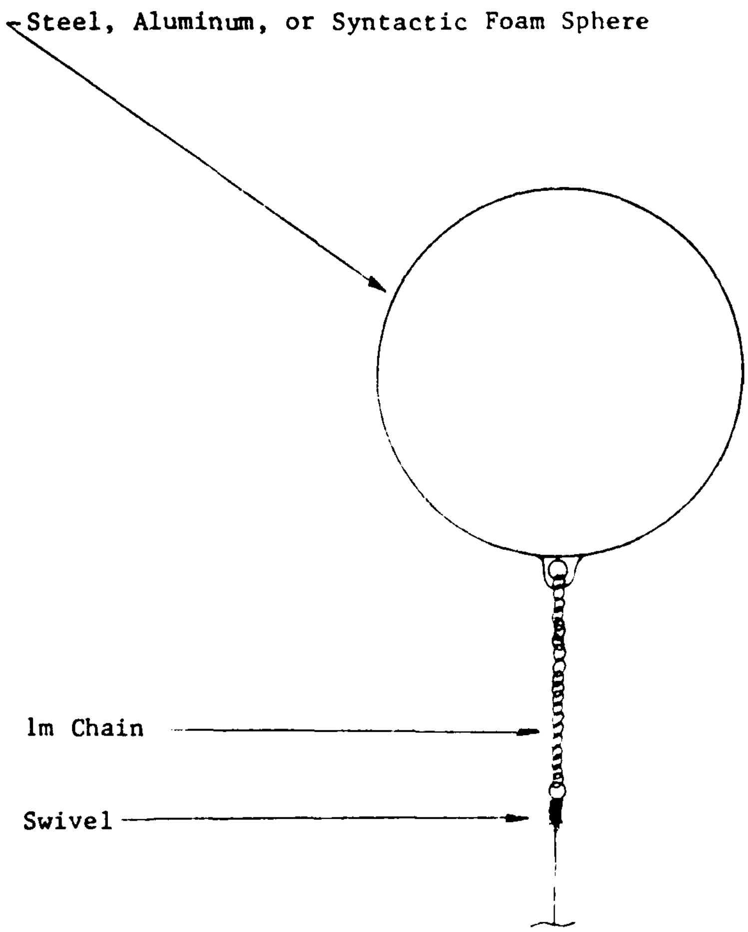

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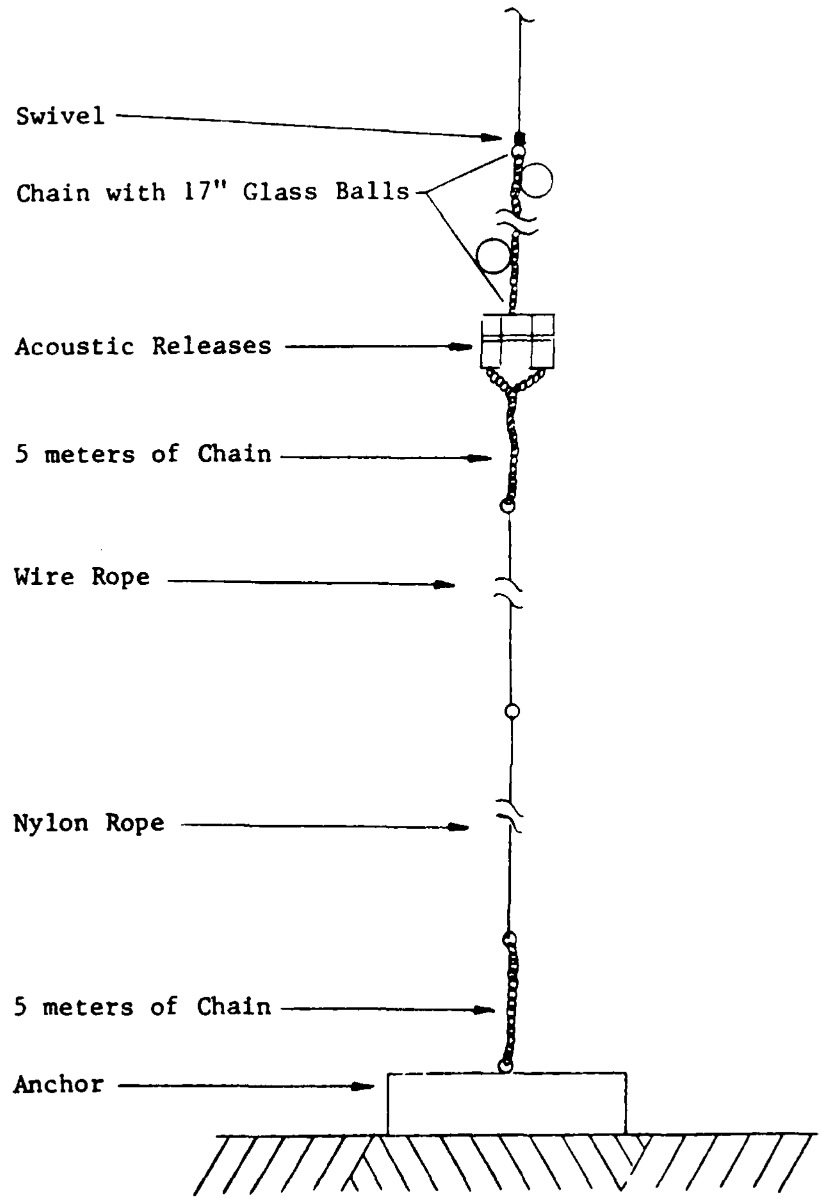

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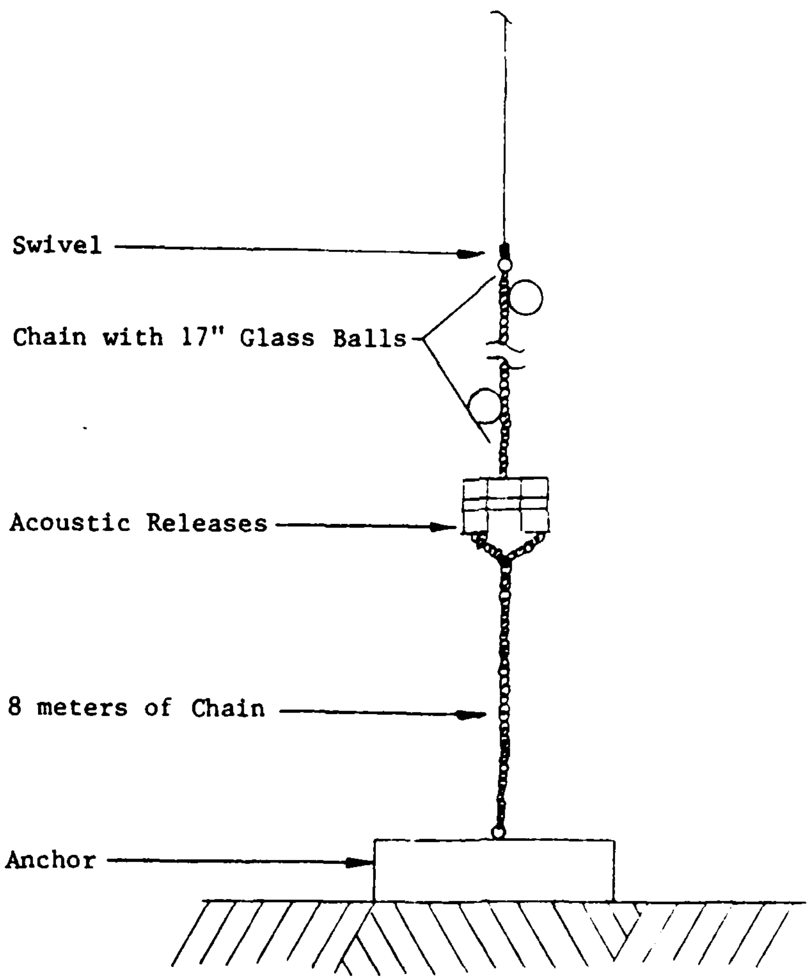

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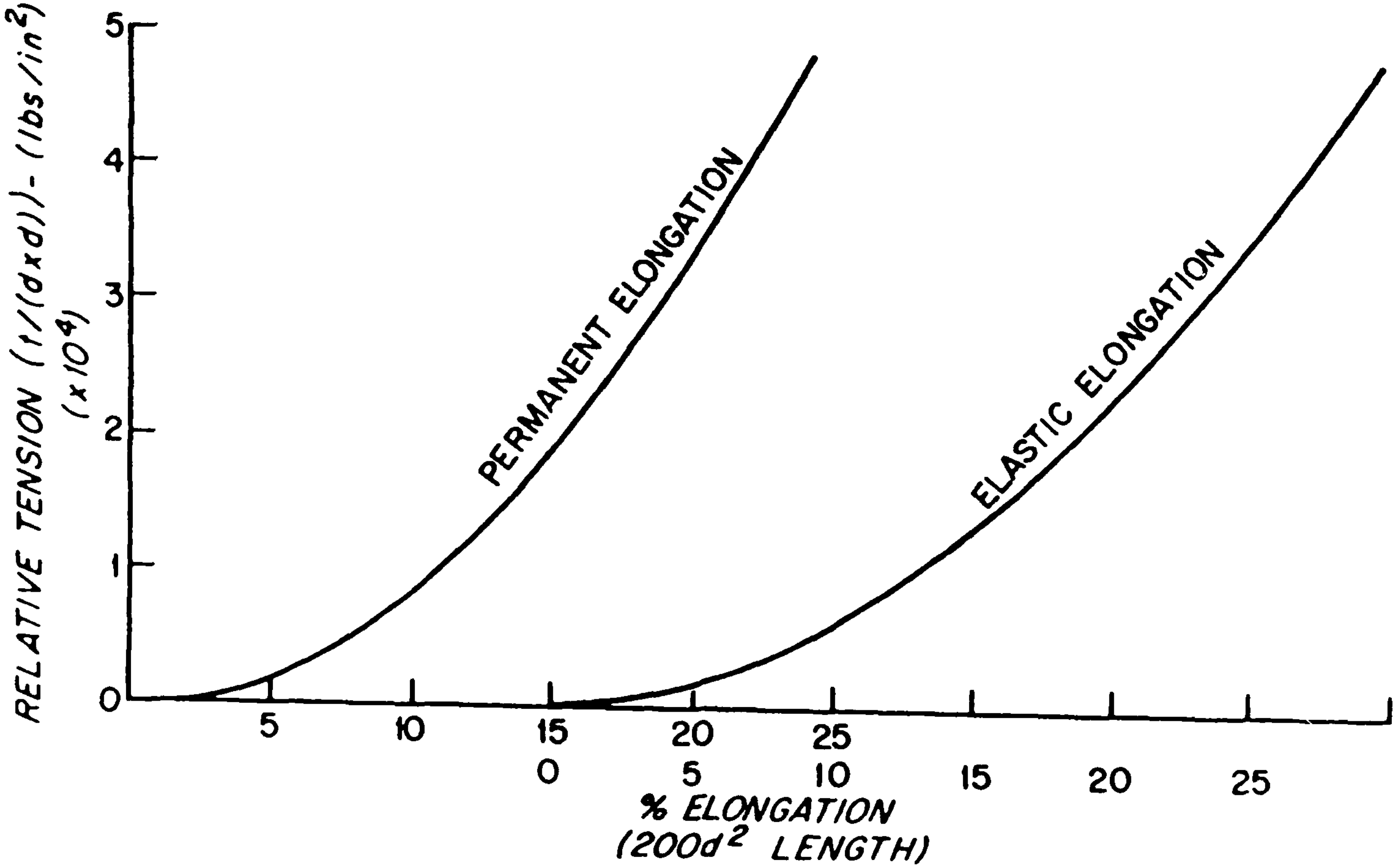

Figure 20: General Stress-Strain Relations - NYLON
(Moller, 1976)

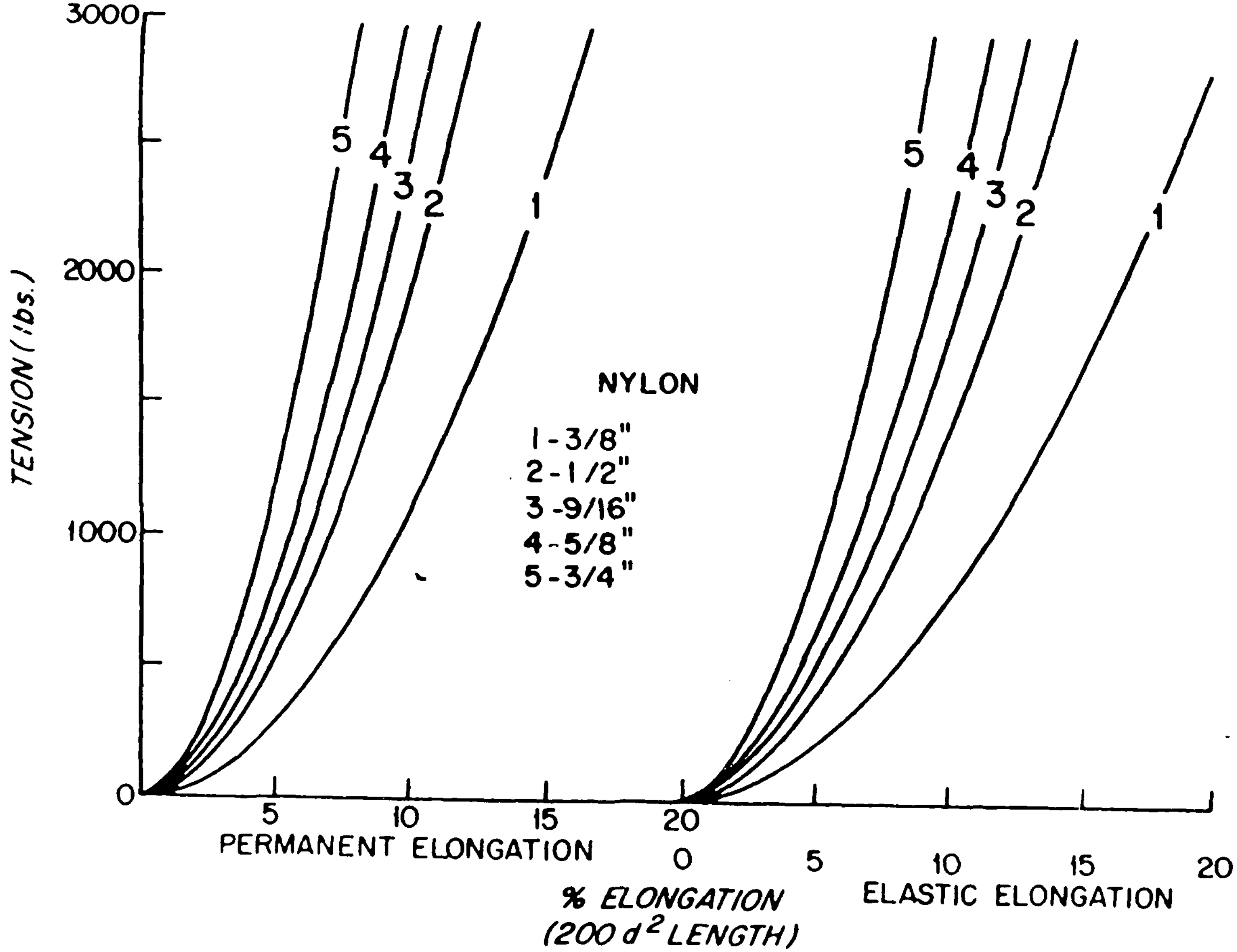

Figure 21: Stretch Curves - NYLON
(Moller, 1976)

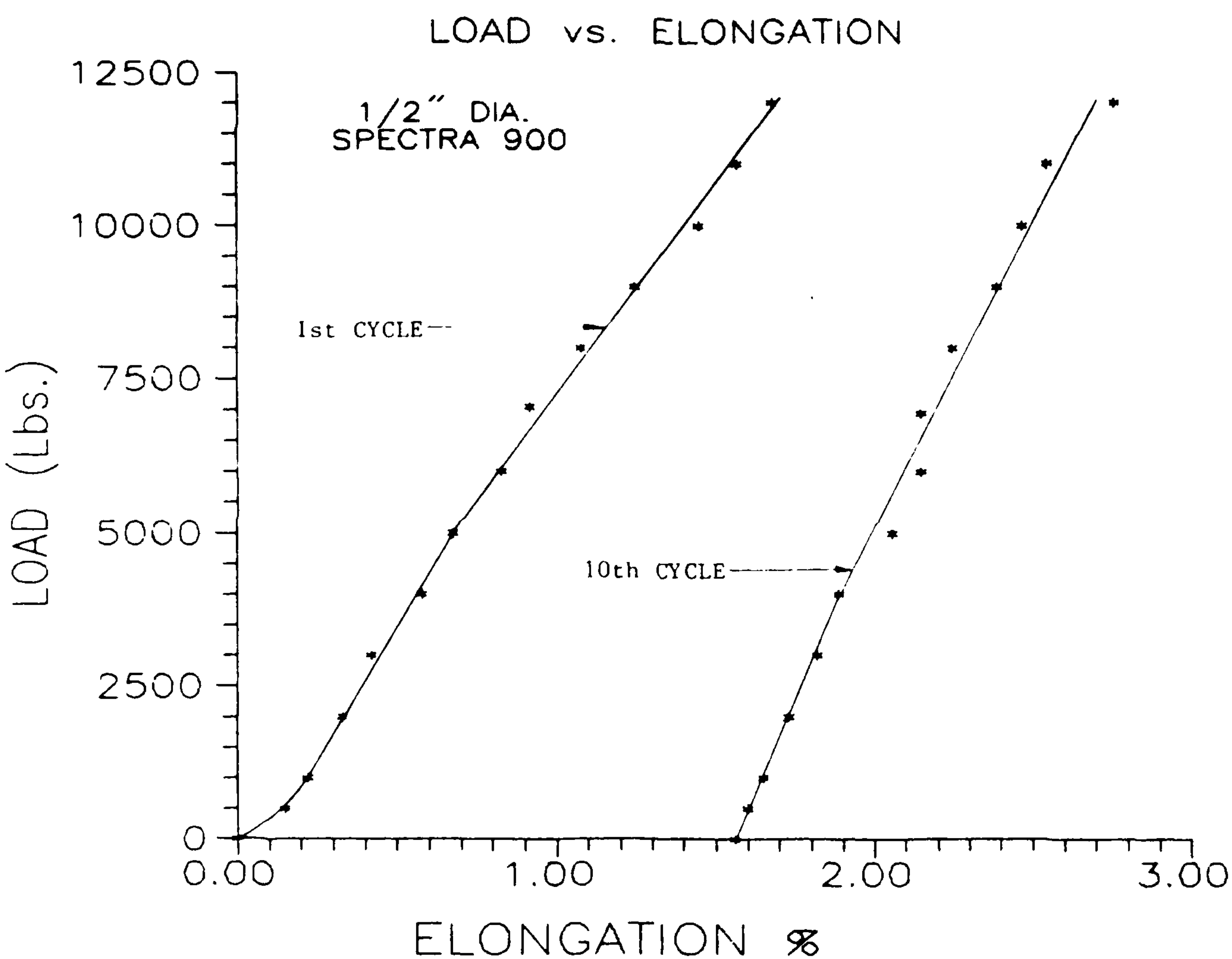

Figure 22: Tenth Cycle Stretch Curves - Spectra 900 and Kevlar 29
(Data courtesy of Whitehill Manufacturing Corp.)

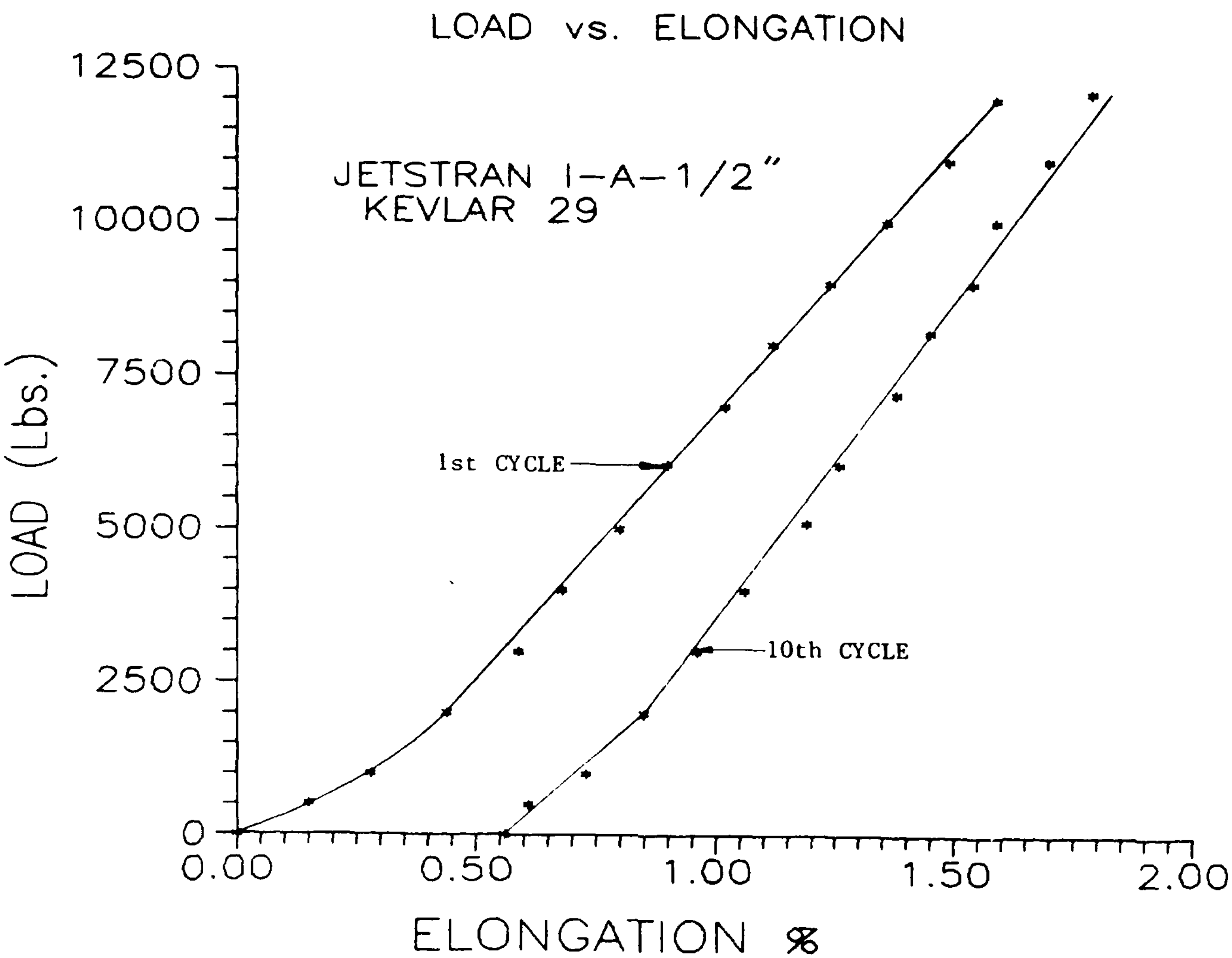

Figure 23: 1st and Tenth Cycle Stretch Curves - Kevlar 29
(Data courtesy of Whitehill Manufacturing Corp.)

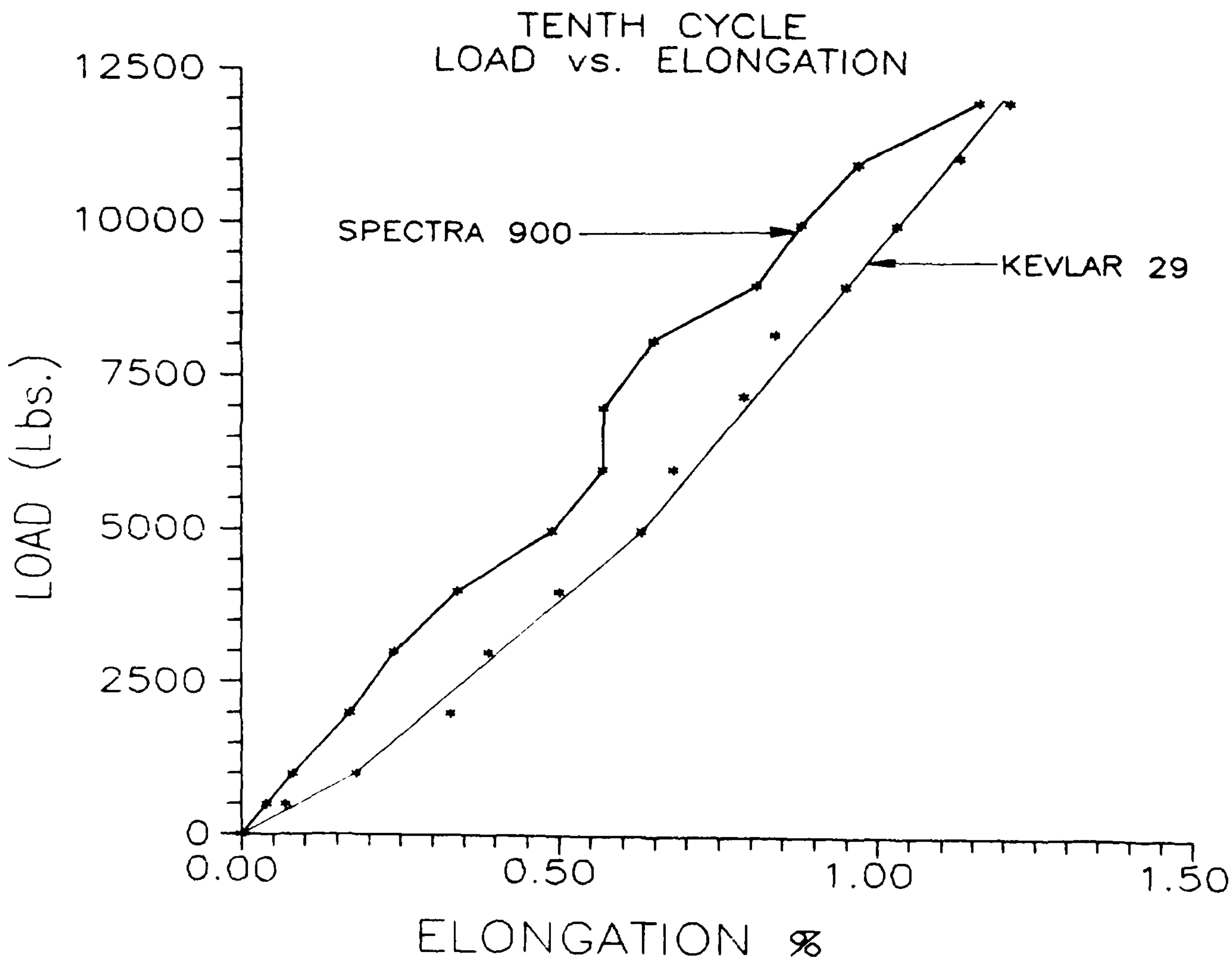

Figure 24; 1st and Tenth Cycle Stretch Curves - Spectra 900
(Data courtesy of Whitehill Manufacturing Corp.)

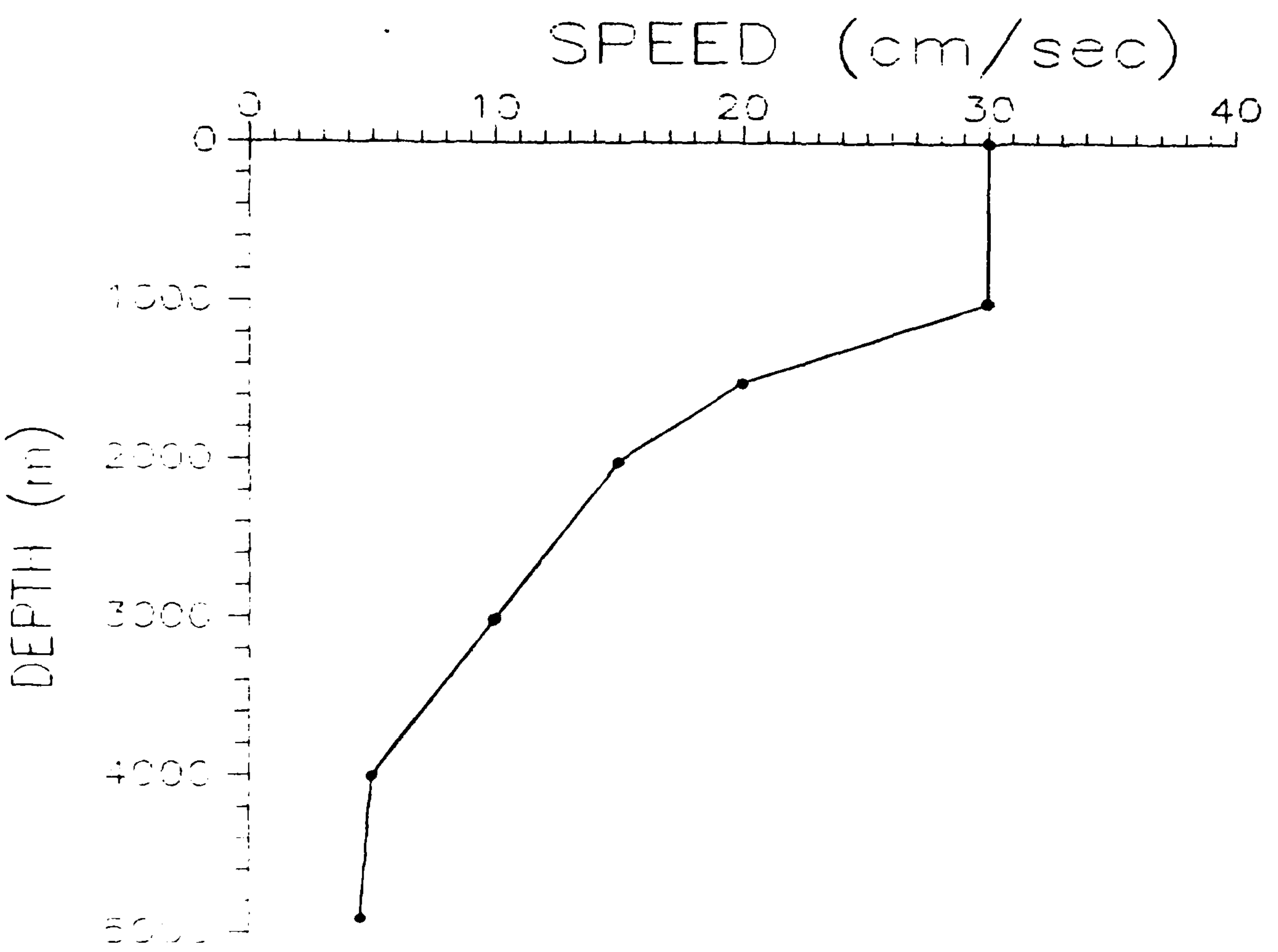

Figure 25: HORIZONTAL CURRENT PROFILE EXAMPLE

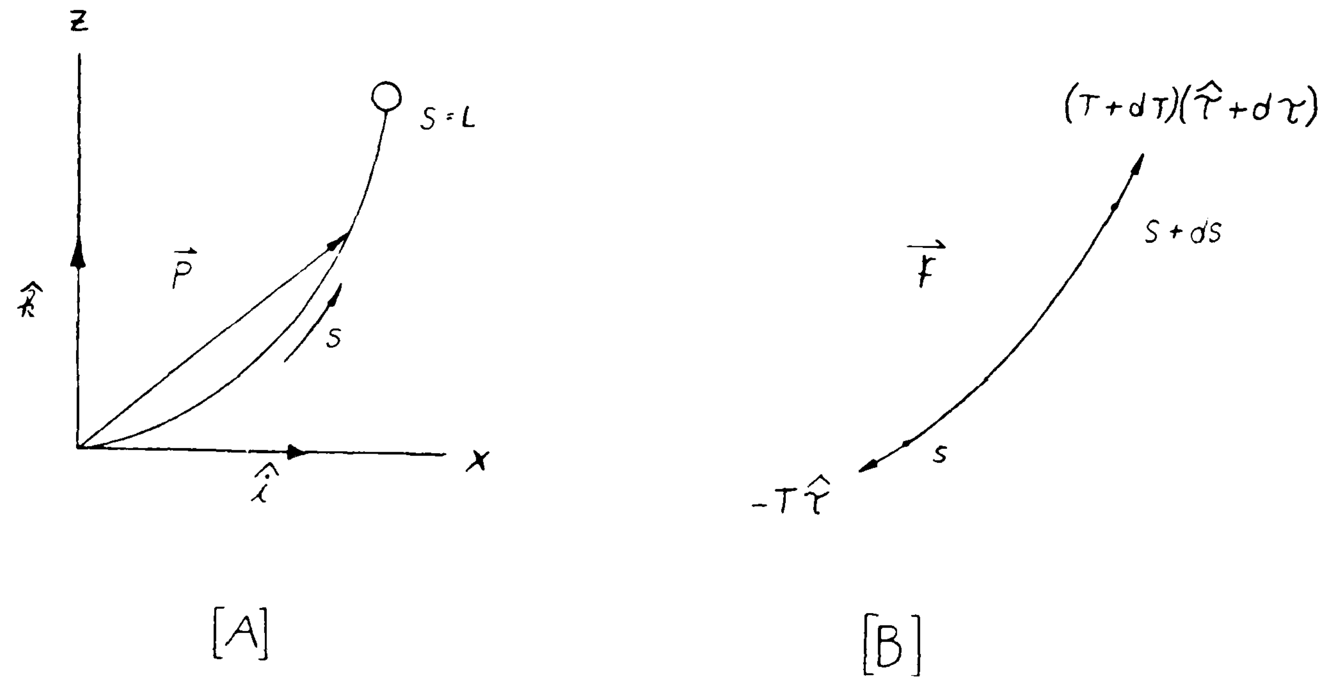

Figure 26: FORCES ON A MOORING CABLE

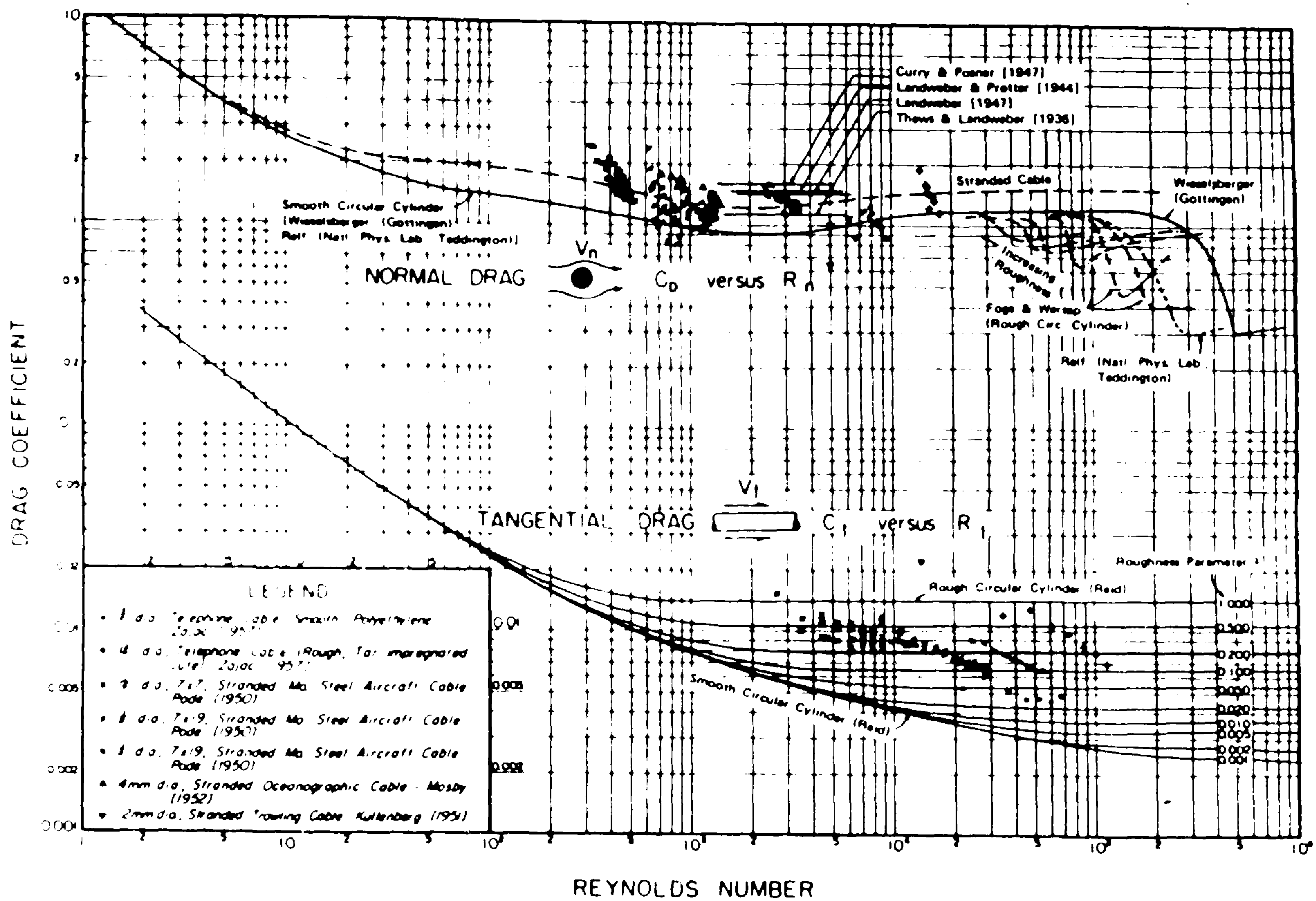

Figure 27: Drag Coefficient vs. Reynolds Number for Flow normal and Tangential to Smooth and Rough Circular Cylinders (Wilson, 1960)

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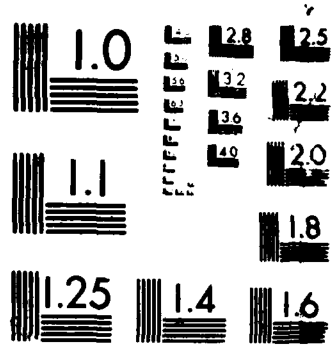

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

No.	Qty.	Part #	Description
0	1	0001	MOORING #1 SAMPLE
1	1	0002	TOP MOORING ASSEMBLY
2	1	0003	BOTTOM MOORING ASSEMBLY
3	--		WIRE ROPE 1500m 3/16"
4	--		KEVLAR ROPE 2000m 1/4"
5	4		VACM
6	1		TOMOGRAPHIC TRANSCEIVER
7	--		STRUT FAIRING 505m
8	A/R		½" SHACKLES
9	A/R		½" SLING LINK
10	A/R		COTTER PIN 316 SS

Figure 29

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No.	Qty.	Part #	Description
0	1	0002	TOP MOORING ASSEMBLY
1	1		2000 Lb. SYNTACTIC FOAM SPHERE
2	1		5m 3/8" CHAIN
3	1		SWIVEL
4	A/R		½" SHACKLE
5	A/R		½" SLING LINK
6	A/R		COTTER PIN 316 SS

Figure 30

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No.	Qty.	Part #	Description
0	1	0003	BOTTOM MOORING ASSEMBLY
1	1		3000 Lb. MACE ANCHOR
2	2		5m ½" CHAIN
3	1		20m 3/4" NYLON ROPE
4	--		1034m ¼" WIRE ROPE
5	2		ACOUSTIC RELEASE
6	1		37m 3/8" CHAIN
7	25		17" GLASS BALLS
8	1		SWIVEL
9	A/R		½" SHACKLE
10	A/R		½" SLING LINK
11	A/R		COTTER PIN 316 SS

Figure 31

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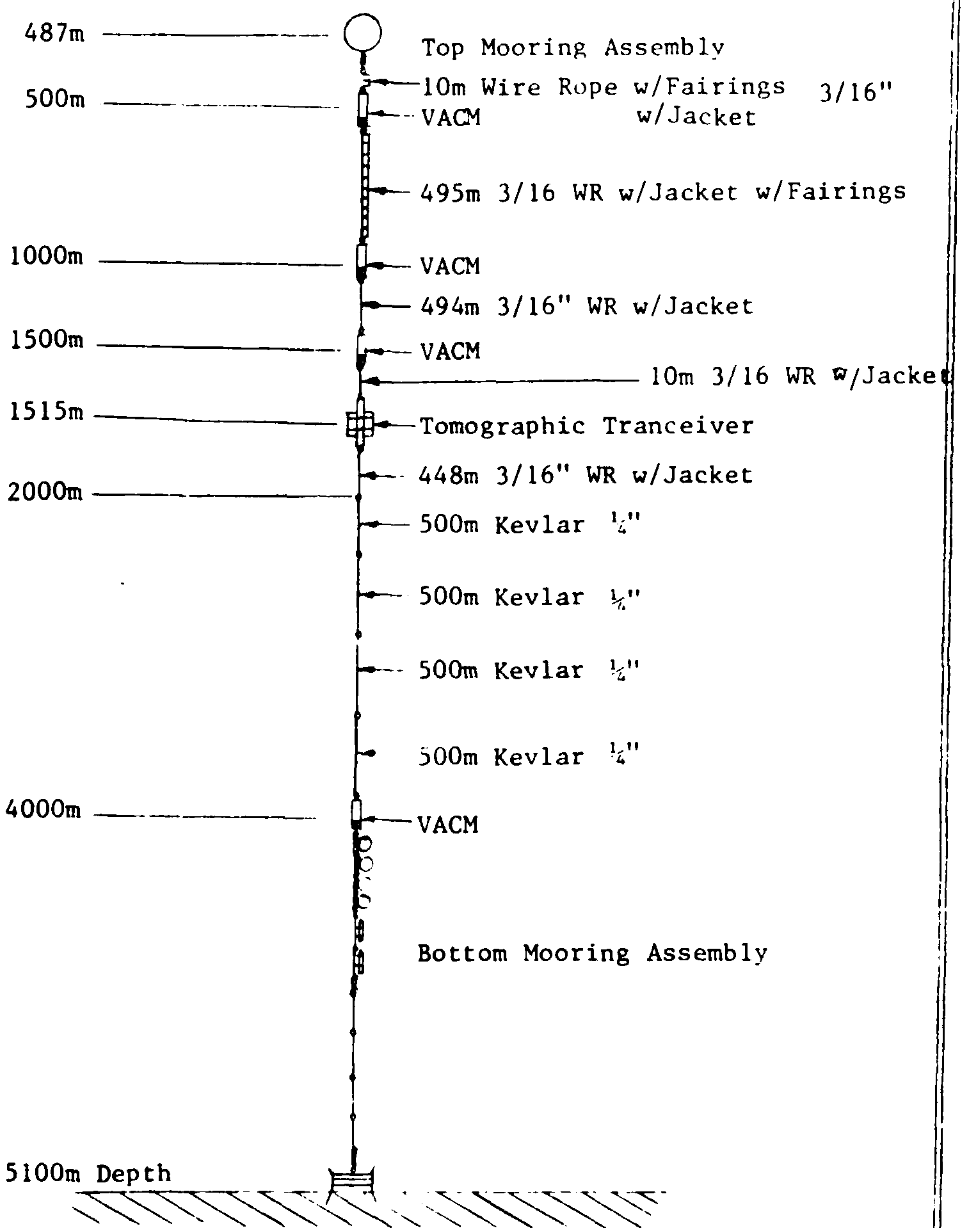
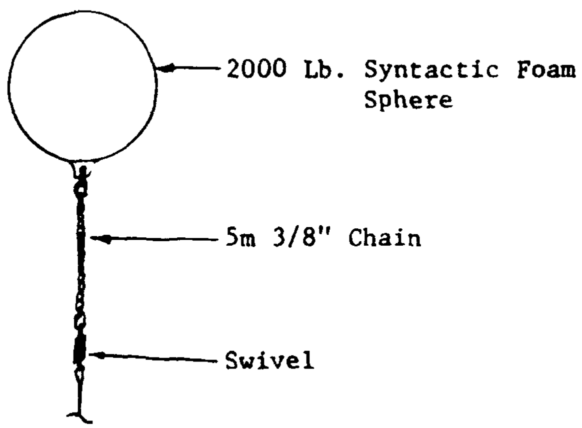


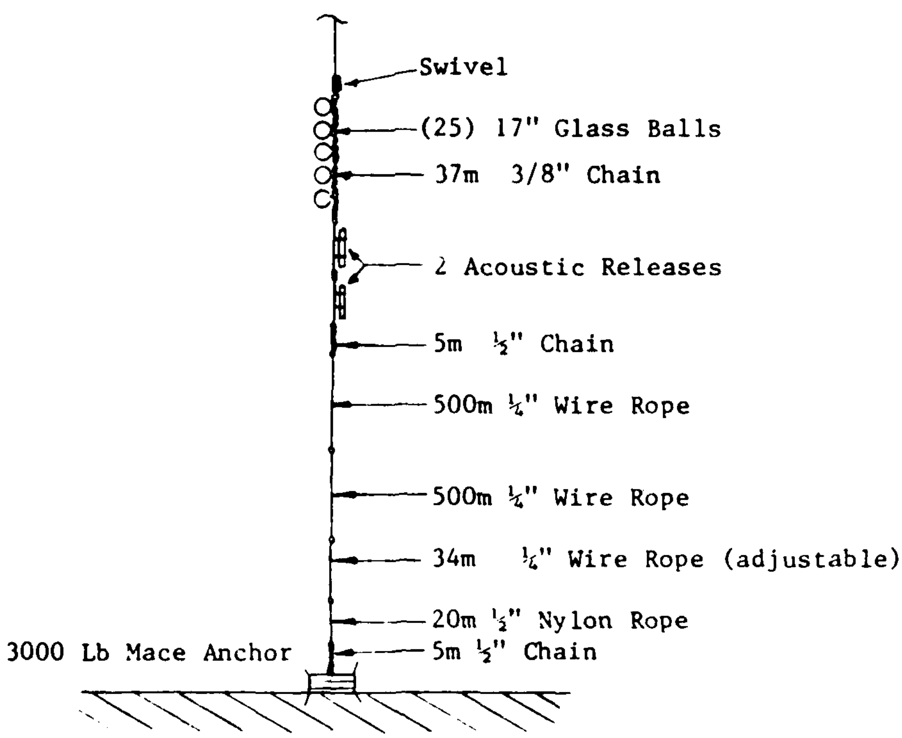
MOORING #1 : SAMPLE Figure 32

DATE:	CHECKED:	University of Miami (RSMAS) OEN/AMP		
DRAFT:	APPVD:	DWG. #: 0001	REV.:	SHEET OF



TOP MOORING ASSEMBLY Figure 33

DATE:	CHECKED:	University of Miami: RSMAS) OEN AMF		
DRAFT:	APPVD:	DWG. #: 0002	REV.:	SHEET OF



BOTTOM MOORING ASSEMBLY Figure 34

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Appendix B: Glossary

Backward Chaining: A control strategy that regulates the sequence in which inferences are drawn. With a rule-based expert system the chaining is initiated by a goal rule and then attempts to satisfy this goal. This method backs up through "if" clauses in a rule to determine whether true or correct. This then guides the system to analyze other rules of plausible "if" clauses.

Breadth-First Search: A strategy where all of the rules or objects at the same hierarchy level are investigated before other rules at lower levels are checked.

Certainty Factors: A confidence factor or numerical weight attributed to a relationship or fact denoting the confidence one has on the information of the relationship or fact (0 to 100% confidence true).

Depth-First Search: A strategy where one rule or object, at the highest level in a hierarchy of rules or objects, is investigated. The rules or objects directly below the one being examined are analyzed next. The expert system will search a single branch in the decision tree until encountering the end, before moving on to another rule.

Explanation and Justification (Mid-Run explanation): The ability to stop the routine at the user's request and explain where it is, what is going on and what the system will seek to accomplish.

Forward Chaining: A control strategy that regulates the sequence in which inferences are drawn. With a rule-based expert system the chaining begins by trying all rules where the "if" clauses are true. Then checks other rules that are possibly true given the previous true clauses. This proceeds until until all possible avenues are searched and a goal is satisfied or an end of the rules encountered.

IF-Then Rules: A relationship among a set of facts.

Traces and Probes: To facilitate the knowledge engineer when developing a knowledge base. Allowing the trace of a run session or probing a point of trouble or error.

The **User Interface** allows the user to communicate with the system. All questions and answers are mediated through this interface. The interface is typically a keyboard and a monitor. This is where the declarative knowledge is entered.

The **Declarative Knowledge** is the knowledge that the user enters through dialogue with the expert system to establish what facts are true at the present time.

The **Explanation System** explains how a particular conclusion was arrived at. This system also displays the line of reasoning that was used to make a particular decision.

The **Knowledge System** acquires the knowledge about the

area of interest from experts, knowledge engineers, libraries, data bases and any other sources of information.

The **Inference Engine** is the main part of an expert system. The inference engine's main function is to draw inferences and to control the activities going on in the system while a consultation is in process.

The **Knowledge Base** is the area of knowledge where human expertise is stored. Establishing the Knowledge Base is the most important and time consuming task in the construction of an expert system. Components of the Knowledge Base are [Das, 1986]:

- Control Knowledge
- Judgmental Knowledge
- Algorithmic Knowledge
- Factual Knowledge

Control Knowledge is responsible for the control of execution of other knowledge such as Judgmental, Algorithmic, or Factual Knowledge. The Control knowledge also controls and coordinates the processes and activities in the knowledge base system. The Control knowledge also is used to index the location of a particular piece of knowledge. This happens when the inference engine accesses the Knowledge Base in order to draw inferences, or when trying to satisfy requests of various knowledge posted on the Blackboard.

Judgmental Knowledge - Consists of heuristic or

rules-of-thumb types of knowledge. This type of knowledge is very difficult to be programmed into well defined procedures. Judgmental knowledge is quite valuable in the reduction of the search of a suitable solution for a particular problem. The types of Knowledge included in this area are:

- Method of practice
- Economic, cost considerations
- Regulatory requirements
- Code guidelines.

Algorithmic Knowledge - Consists of analysis and evaluation of the problem based upon the use of physical laws (the evaluation of the response to an externally applied load on a beam). This knowledge also analyzes and accesses other types of evaluation programs:

- analysis programs
- data base management
- graphics programs

Factual Knowledge- Consists of the knowledge that is the most primitive and clearly defined. This knowledge is found in catalogs and handbooks, such as the selection of materials and their properties. The manipulation of this data is most easily done through basic data base management.

The **Blackboard** is best considered as the working memory of the system. The Knowledge base, Inference

Engine and the User Interface are able to access the Blackboard. Once the consultation has begun, each portion of the system issues and receives instructions and results by way of the Blackboard. The inference engine monitors the blackboard and will activate various components of the knowledge.

Appendix C: *** LINE OF QUESTIONING ***

NOTE: -->-- denotes branch to an external program
━━━ denotes the main expert system pathway.

Introduction with opening information and usage info:

Purpose of the mooring/buoy design expert assistant.
Parameters of what the system is able to accommodate.
Limitations, capabilities and regimes of the system.
List of the information that will be needed to run the system:
- Title, Design Engineer, Project number, Water depth, Project site, Shark bite consideration
- Ambient currents(profile), Number of instruments,
- Types of instruments, Depths of each instruments,
- Motion restrictions of specific instruments,
- Seafloor material, seafloor topography, duration of deployment period.

---->--

external program Introduc.pas

Enter Title, Designer, Project Number
Latitude and longitude coordinates.
water depth.

Check if latitude is in fishbite zone.
Should fishbite be a consideration ?

Enter # of experiment stations

What are the instrument categories ?
Listed are various categories of instruments to be selected. If not listed OTHER is selected to check other instruments not specified below.

SELECT ALL THAT APPLY:

Current meters Hydrophones Depth recorders
Tension recorders Releases Inclinometers
Pressure recorders OTHER

If OTHER is specified, display current OTHER listing if none available or type desired is

unavailable then obtain the category name and the technical data on the instrument and add it to a data base.

External program: Instrmts.pas

This external program selects and/or adds new instruments to the data bases in the expert system.

-Select specified equipment from each individual data base of the instrument. (ie. a specific type of current meter) Continue until all databases are satisfied.
-Specify quantity of each instrument.
-Do you wish a second backup CABLE RELEASES

If OTHER is specified then obtain the technical data on the instrument and add it to a data base.

Send information to Knowledge base on each instrument type for later utilization in analysis.

External Program: Position.pas

This routine positions the instruments allowing for multiple types of instruments at one location.

At what depth is each instrument positioned
Loop until done. position all but RELEASES

Are their Motion Restriction of the experiments ?

NO

YES

Which experiments have motion Restrictions ?

External program: MotionR.pas

This external routine obtains the motion restrictions and checks for basic error in excessive constraints.

At what depth is the experiment with the motion restriction ? check each experiment/instrument.
Maximum DIP?
Maximum Excursion?
Maximum Angle

Preliminary check to see if the restrictions are to severe even for none current designs.

Calculate what is the minimum constraint

Are their any Ambient Currents?

YES

NO

unknown

Which direction is the Prevailing Current?
N,NE,E,SE NNE,ENE,ESE,SSE
S,SW,W,NW NNW,WNW,WSW,SSW

unknown

NO

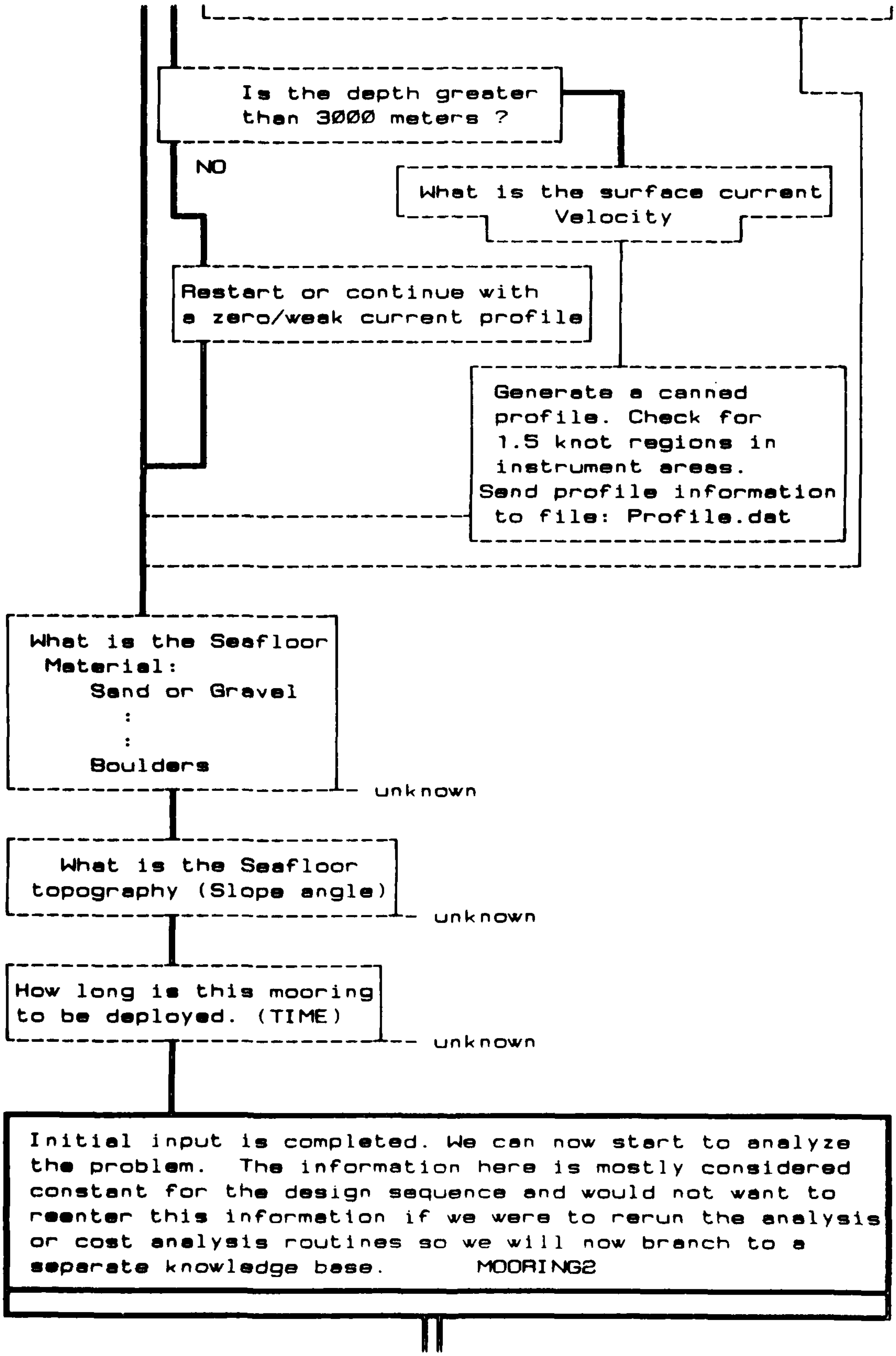
Do you have current information at this location? ie. current velocity at different depths. It is necessary to obtain the ocean profile for accurate analysis.

YES

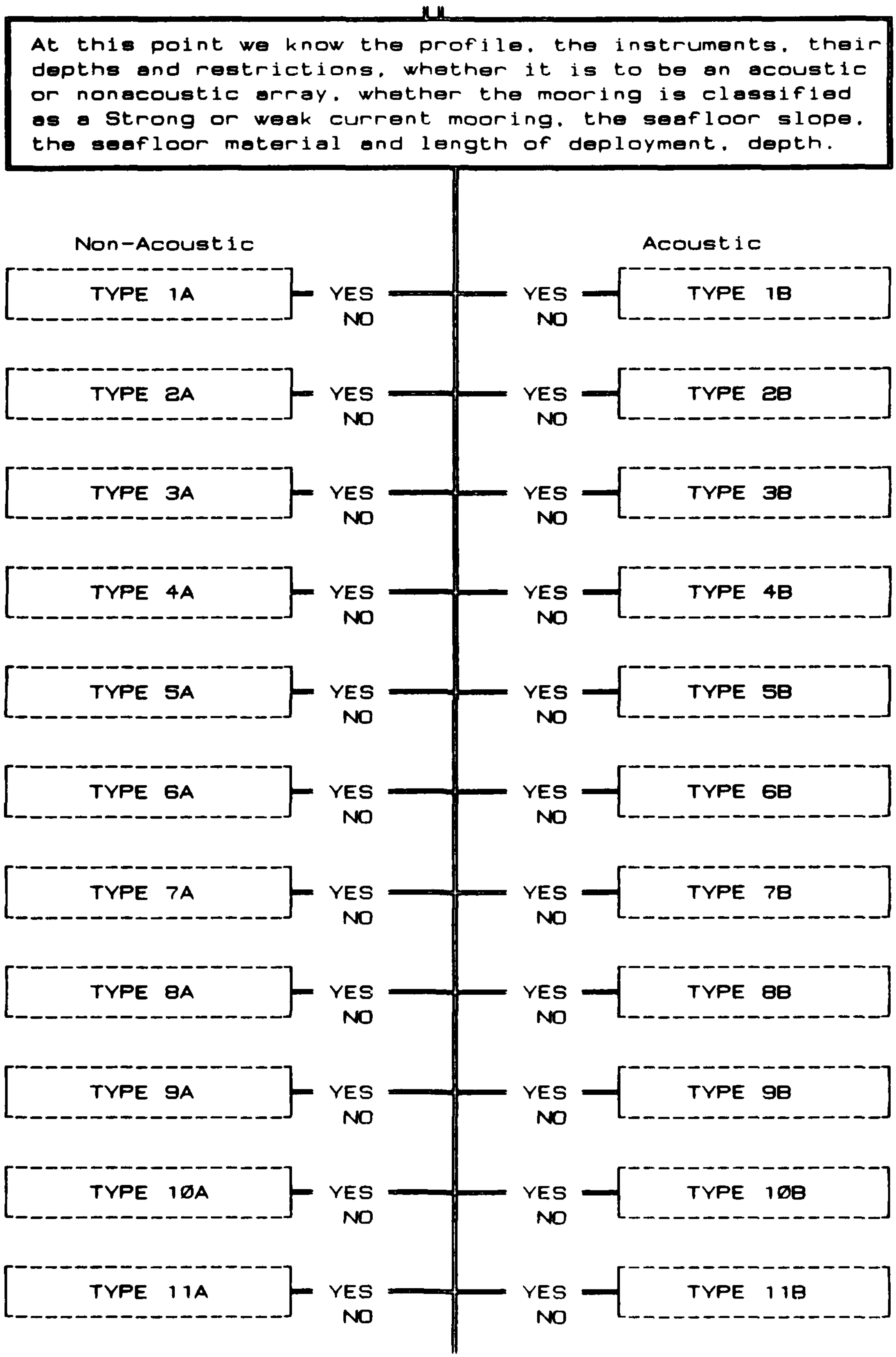
How many points of data do you have?

External program: Profile.pas

to obtain setup profile for mooring analysis
Enter depths and Velocities for each profile point. Check depths of each instrument with velocities. if velocities are over 1.5 knots at any instrument then the mooring is classified in the Strong Current region.
Data base file : Profile.dat



Is the depth greater than 3000 meters ?
NO
What is the surface current Velocity
Restart or continue with a zero/weak current profile
Generate a canned profile. Check for 1.5 knot regions in instrument areas. Send profile information to file: Profile.dat
What is the Seafloor Material:
Sand or Gravel
:
:
Boulders
unknown
What is the Seafloor topography (Slope angle)
unknown
How long is this mooring to be deployed. (TIME)
unknown
Initial input is completed. We can now start to analyze the problem. The information here is mostly considered constant for the design sequence and would not want to reenter this information if we were to rerun the analysis or cost analysis routines so we will now branch to a separate knowledge base. MOORING2


At this point we know the profile, the instruments, their depths and restrictions, whether it is to be an acoustic or nonacoustic array, whether the mooring is classified as a Strong or weak current mooring, the seafloor slope, the seafloor material and length of deployment, depth.
Non-Acoustic
Acoustic
TYPE 1A
YES
NO
YES
NO
TYPE 1B
TYPE 2A
TYPE 2B
TYPE 3A
TYPE 3B
TYPE 4A
TYPE 4B
TYPE 5A
TYPE 5B
TYPE 6A
TYPE 6B
TYPE 7A
TYPE 7B
TYPE 8A
TYPE 8B
TYPE 9A
TYPE 9B
TYPE 10A
TYPE 10B
TYPE 11A
TYPE 11B

TYPE 12A — YES / NO — YES / NO — TYPE 12B

TYPE 13A — YES / NO — YES / NO — TYPE 13B

TYPE 14A — YES / NO — YES / NO — TYPE 14B

Initiate buoy design by:
- Calculate total instrument weight.
- Obtain the drag coefficients of the instruments.
- Calculate the areas of the instruments.
- Calculate preliminary cable/rope/chain lengths.
- Calculate the preliminary cable/rope/chain sizes.
- Calculate the maximum amount of flotation the wire /cable is limited to for the cable presently being analyzed.
- Calculate the preliminary weights of cables/chain.
- Calculate the preliminary area of the buoy/buoys.
- Calculate the preliminary buoyancy of primary and backup flotation and then recalculate the chain lengths at the flotation regions. Recalculate the weights and buoyancy to see if buoyancy is adequate for the new weights. Recalculate until satisfied.
- Calculate the preliminary weight of anchor.
- Calculate the preliminary area of anchor.

Calculate Launch Transients to find the maximum stress force on the mooring system.

Calculate drag forces, current forces, weight forces on the mooring system with analysis on each instrument and segment of the mooring.
If the maximum stress force is greater than the working stress allowed on the cables/chain then increase their sizes and recheck the launch transient forces. This force should be the maximum on the system unless constraints on the system require greater buoyancy and possibly larger cables/ropes.

Setup preliminary design, utilizing all information except current profile data. The information here should be enough to produce a complete design for a no current design.

External Program PreSetup.PAS

This routine is to setup a datafile with components of the mooring under a no current condition. The file should be as complete as possible to allow for
1) a completed design ready for plotting (no current)
2) initial design for later modifications in current situations
3) analysis by other routines if expert system desires

Information stored in file: PreSetup.DAT

The information in the file PreSetup.DAT is not to be changed under any circumstances except in the case of a satisfied check #1 found in the dynamic analysis. This file will be the starting point of other designs when a failure of the mooring design occurs due to an over constraint specification by the user or by the manufactures constraint specifications.

Is there profile data? — YES

NO

Are their motion restrictions ? — YES

NO

Check motion restrictions.

External program : analysis.pas

Obtaining the profile data from the data base where located:

A straight line profile approximation is used in the analysis of the currents.

-Current velocities are generated for each segment/instrument in the mooring system.
-Gravitational and hydrodynamic drag is calculated for each segment/instrument.
-Equilibrium Conditions of each discrete segment are calculated iteratively by balancing the gravitational and drag forces with the external restraining forces.
-Elongation and Elastic Properties of wire rope and synthetic rope.

-Segment displacement generated.
-Adjustment of the component lengths.
-Back-up recovery buoyancy recalculation

The initial profile/dynamic analysis is obtained.

Check #1 for not meeting manufactures constraints such as a 15° operation angle for current meters of 45° angle for inclinometer operation
Check #2 for not meeting user/designer constraints on various instruments.

Failure of check #1: add more buoyancy and then reanalyze but also remembering the maximum amount of flotation permitted on the specified mooring line.
IF flotation required goes beyond the maximum allowed a new cable must be chosen from the data base then reinitialize and reanalyzed.
If the reinitialize and reanalysis fails continue until one succeeds. If they all fail inform the user that the velocities in the region are such that a mooring utilizing the specified instruments is impossible.

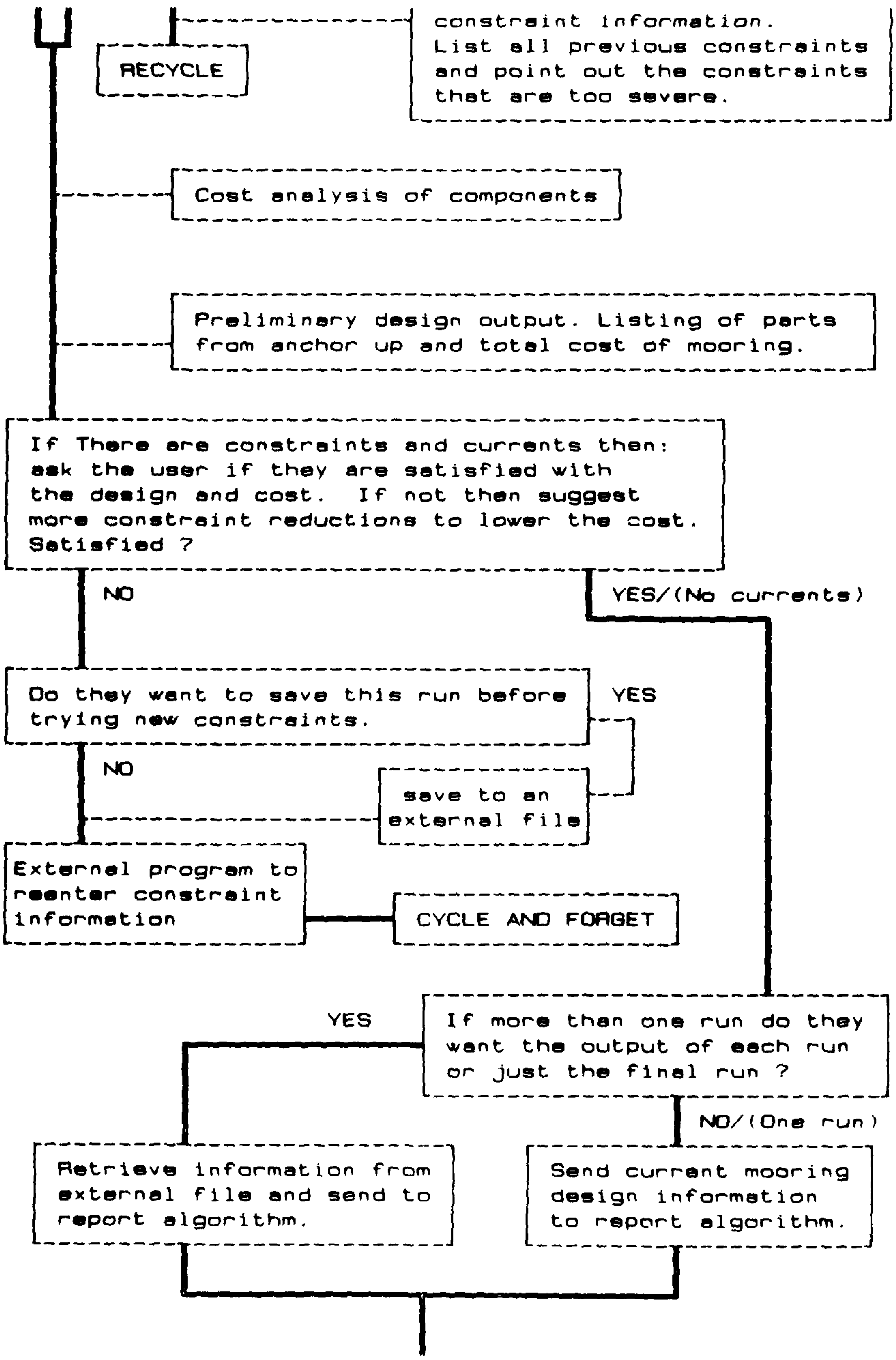
Failure of check #2: add more buoyancy or switch from primary glass ball flotation to syntactic foam sphere flotation and then reanalyze while remembering the maximum possible flotation permitted on the line. As above, if the flotation is greater than the maximum permitted then obtain the next larger cable from the cable /rope data base then reanalyze.

Are the constraints on any instrument to severe. Causing the mooring design to fail by end of data base encountered. ie. no cable large enough to handle parameters.

NO YES

Give warning message. inform user which instruments have too severe constraints on the mooring system. Give suggestions on what types of constraints are at least somewhat reasonable. Also give reasons behind every comment.

External Program to reenter



constraint information.
List all previous constraints and point out the constraints that are too severe.
RECYCLE
Cost analysis of components
Preliminary design output. Listing of parts from anchor up and total cost of mooring.
If There are constraints and currents then: ask the user if they are satisfied with the design and cost. If not then suggest more constraint reductions to lower the cost. Satisfied ?
NO
YES/(No currents)
Do they want to save this run before trying new constraints.
YES
NO
save to an external file
External program to reenter constraint information
CYCLE AND FORGET
YES
If more than one run do they want the output of each run or just the final run ?
NO/(One run)
Retrieve information from external file and send to report algorithm.
Send current mooring design information to report algorithm.

Restart or
END ?

Appendix D:

TITLE Mooring Design Assistant Version Ø.1 DISPLAY

```
MOORING/BUOY --- KNOWLEDGE BASE      Page 1 of 4

              S u b - S u r f a c e

        M o o r i n g / B u o y   D e s i g n

           E x p e r t   A s s i s t a n t

                    Version Ø.1

          A knowledge base for the INSIGHT 2+
        Expert System Development Environment

                   RSMAS - OEN
                 STEPHEN L. WOOD

   Press Function Key 1 to view additional pages.

   Press Function Key 3 STRT to start the knowledge base.
```

```
MOORING/BUOY --- KNOWLEDGE BASE      Page 2 of 4
------------------------------------------------------------

This program designs a single point subsurface mooring
for multiple purposes.  Any number of experiments can be
deployed on the mooring.  This program calculates all
necessary technical data in the mooring analysis, selects
appropriate equipment and presents a design which is the
cheapest to implement.  Both acoustic and non-acoustic
arrays can be designed for.  This system also allows the
user to specify the instruments to be used along with
specialized equipment the scientist would like to use.
High and low current regimes are taken into account along
with extreme depths.

     Press Function Key 1 to view additional pages.
------------------------------------------------------------
   Press Function Key 3 STRT to start the knowledge base.
```

MOORING/BUOY --- KNOWLEDGE BASE Page 3 of 4

Information needed to be supplied by the USER:

- Title
- Design Engineer
- Project Number
- Water Depth
- Ambient Currents
  Direction
  profile - depth
  velocity
- Number of Instruments
- What are the Instruments
- What Depth are the Instruments
- Are there motion restrictions with a specific instrument beyond the manufactures restrictions
- What is the Seafloor Material
- What is the seafloor topography
- How long is the mooring to be deployed (duration)

Press Function Key 1 to view additional pages.

Press Function Key 3 STRT to start the knowledge base.

MOORING/BUOY --- KNOWLEDGE BASE Page 4 of 4

The above information is needed to have a complete knowledge of the area where deployment is desired. If only some of the information is available, then only answer with what you have and enter UNKNOWN for the other answers, or give a "best" guess to the question.

Press Function Key 1 to view additional pages.

Press Function Key 3 STRT to start the knowledge base.

```
!
!------------------SHARED FACTS---------------------------
!  Facts that are shared between chained knowledge bases are
!  in file MOORSHAR.PRL
!---------------------------------------------------------
$MOORSHAR.PRL

!------------------DECLARATIONS---------------------------
!   Here we are declaring some facts as specific types to
!   ensure that are used properly.
!---------------------------------------------------------
SIMPLEFACT They have the info
AND        Have we positioned other instruments

NUMERIC    Depth Again
AND        How many data points

STRING     type
AND        What is the direction of the surface current

OBJECT     The seafloor material

INIT The seafloor material IS S1
AND  The seafloor material IS S2
AND  The seafloor material IS S3
AND  The seafloor material IS S4
AND  The seafloor material IS S5
AND  The seafloor material IS S6
AND  The seafloor material IS S7

!-----------------------------------------------------
! Instrument is "multi-attributed" because the attributes
! can be simultaneously true
!-----------------------------------------------------
MULTI  The Instrument

1. The Mooring System can be evaluated

!--------------------------------------------------------
!   This rule initiates the expert system and checks if we
!  have the information to create the design.
!   Once satisfied then the analysis knowledge base
!  MOORING2 is activated and assumes control of the design.
!--------------------------------------------------------
RULE Introduction
CALL Introduc
RETURN Title
RETURN Designer
RETURN Contract#
RETURN Latitude
RETURN Longitude
RETURN Depth
IF We have the answers
AND You are ready to continue analysis
```

```
THEN The Mooring System can be evaluated
AND CHAIN MOORING2
ELSE DISPLAY need info

!-----------------------------------------------------------
!  This rule obtains the various aspects needed such as
!  the instruments, currents, restrictions etc..
!-----------------------------------------------------------
RULE For obtaining the answers
IF  We have the instruments
AND We have the motion restrictions
OR  We have no motion restrictions
AND We have the currents
OR  We have no currents
AND We have the seafloor material
OR  We do not know the seafloor material
AND We have the seafloor topography
OR  We do not know the seafloor topography
AND We have the deployment duration
THEN We have the answers
ELSE DISPLAY something does not work

!-----------------------------------------------------------
! These rules obtain the currents
!-----------------------------------------------------------
RULE For obtaining the ambient currents
IF Are there any ambient currents
AND ASK What is the direction of the surface current
AND We have the profile
OR The profile is generated
AND ACTIVATE I&C.COM
DISK DATA.DAT
RETURN Weak currents
RETURN Strong currents
THEN We have the currents
AND NOT We have no currents
ELSE We have no currents
AND Weak currents
AND NOT Strong currents

RULE For obtaining the current profiles
IF Do you have the current profile
AND We have the current profile data
THEN We have the profile
AND NOT The profile is generated

RULE For obtaining the profile data
IF How many data points > 4
AND How many data points < 15
AND ACTIVATE PROFILE.COM
DISK DATA.DAT
SEND Depth
SEND How many data points
SEND What is the direction of the surface current
```

```
THEN We have the current profile data
ELSE Wrong number of data pts

RULE For generating the profile
IF Depth > 3000
AND ACTIVATE PROGEN.COM
DISK DATA.DAT
SEND Depth
SEND What is the direction of the surface current
THEN The profile is generated
AND NOT We have the profile
ELSE DISPLAY Profile is not possible

!------------------------------------------------------------
!  These rules obtain the instruments
!------------------------------------------------------------
RULE For obtaining the number of instruments
IF How many instruments >= 0
AND We have selected the instruments
AND We have determined if acoustic or nonacoustic
THEN We have the instruments

RULE For selecting the instruments
IF The Instrument IS Current Meters
OR The Instrument IS Tension Recorders
OR The Instrument IS Depth recorders
OR The Instrument IS Inclinometers
OR The Instrument IS Hydrophones
OR The Instrument IS Transducers
OR The Instrument IS Transponders
OR The Instrument IS Other
AND We have specified the instruments
THEN We have selected the instruments
ELSE DISPLAY Instrument Error

RULE For determining acoustic or nonacoustic instruments
IF The Instrument IS Hydrophones
THEN We have determined if acoustic or nonacoustic
AND Acoustic array
AND NOT NonAcoustic array
ELSE We have determined if acoustic or nonacoustic
AND NonAcoustic array
AND NOT Acoustic array

RULE For specifiing the instruments
IF We have the Current Meters
OR We have no Current Meters
AND We have the Tension Recorders
OR We have no Tension Recorders
AND We have the Depth Recorders
OR We have no Depth Recorders
AND We have the Inclinometers
OR We have no Inclinometers
AND We have the Hydrophones
```

```
OR We have no Hydrophones
AND We have the Others
OR We have no Others
THEN We have specified the instruments

RULE For selecting the Current Meters
IF The Instrument IS Current Meters
AND type := CURRENTM
AND FORGET We have obtained and positioned the instruments
AND We have obtained and positioned the instruments
THEN We have the Current Meters
AND Have we positioned other instruments
ELSE We have no Current Meters

RULE For selecting the Tension Recorders
IF The Instrument IS Tension Recorders
AND type := TENSIONR
AND FORGET We have obtained and positioned the instruments
AND We have obtained and positioned the instruments
THEN We have the Tension Recorders
AND Have we positioned other instruments
ELSE We have no Tension Recorders

RULE For selecting the Depth Recorders
IF The Instrument IS Depth Recorders
AND type := DEPTHREC
AND FORGET We have obtained and positioned the instruments
AND We have obtained and positioned the instruments
THEN We have the Depth Recorders
AND Have we positioned other instruments
ELSE We have no Depth Recorders

RULE For selecting the Inclinometers
IF The Instrument IS Inclinometers
AND type := INCLINOM
AND FORGET We have obtained and positioned the instruments
AND We have obtained and positioned the instruments
THEN We have the Inclinometers
AND Have we positioned other instruments
ELSE We have no Inclinometers

RULE For selecting the Hydrophones
IF The Instrument IS Hydrophones
AND type := HYDROPHO
AND FORGET We have obtained and positioned the instruments
AND We have obtained and positioned the instruments
THEN We have the Hydrophones
AND Have we positioned other instruments
ELSE We have no Hydrophones

RULE Interface to obtain and position instrument
CALL INSTRMTS
SEND type
RETURN Number of Instruments
```

```
RETURN Type of Instrument
RETURN Length of Instrument
RETURN Area of Instrument
RETURN Weight of Instrument
RETURN Buoyancy of Instrument
RETURN Maximum depth of Instrument
RETURN Drag coefficient of Instrument
RETURN Maximum tension
RETURN Cost of Instrument
ACTIVATE POSITION.COM
DISK DATA.DAT
SEND type
SEND Number of Instruments
SEND Have we positioned other instruments
SEND Type of Instrument
SEND Length of Instrument
SEND Area of Instrument
SEND Weight of Instrument
SEND Buoyancy of Instrument
SEND Maximum depth of Instrument
SEND Drag coefficient of Instrument
SEND Maximum tension
SEND Cost of Instrument
RETURN Top experiment depth
RETURN Bottom experiment depth
THEN We have obtained and positioned the instruments

RULE For selecting Other instruments
IF The Instrument IS Other
AND CALL UDDER
THEN We have the Others
ELSE We have no Others

!-----------------------------------------------------------
!  These rules obtain the motion restrictions on the
!  instruments.
!-----------------------------------------------------------
RULE For obtaining motion restrictions of the instruments
IF Are there motion restrictions
AND We have the motion restriction info
THEN We have the motion restrictions
AND NOT We have no motion restrictions
ELSE We have no motion restrictions
AND NOT We have the motion restrictions

RULE For obtaining the motion restrictions
ACTIVATE MotionR.com
DISK DATA.DAT
SEND How many instruments
THEN We have the motion restriction info

!-----------------------------------------------------------
! This rule obtains the seafloor information.
!-----------------------------------------------------------
```

```
RULE For obtaining the seafloor material
ASK The seafloor material
THEN We have the seafloor material

RULE For obtaining the seafloor topography
IF The seafloor topography >= 0
THEN We have the seafloor topography
ELSE We do not know the seafloor topography

!------------------------------------------------------------
!  This rule obtains the deployment duration.
!------------------------------------------------------------
RULE For obtaining the deployment duration
IF The deployment duration > 0
THEN We have the deployment duration
ELSE We do not know the deployment duration

!---------------------------------------------------------
!              Display and Text output
!=========================================================
DISPLAY Instrument Error
```

```
                  **** Error ****
  You must select at least one type of instrument!
              This is a FATAL ERROR!!!!
                You must RESTART (F3)
```

DISPLAY Profile is not possible

```
                  **** Error ****
 This program is not capable of generating profiles in
 seas less than 3000 meters in depth.
```

```
Generating profiles in shallow and intermediate zones
ie. Continental Shelf, Continental Slope regions are
impossible due to such extreme conditions found in
those regions.  Such large variations make the use of
"canned" algorithmic routines useless and very inaccurate
You must obtain the profile information and rerun the
program.

Continuing: F2 (CONT) will proceed to generate a design
with no ambient currents.

Restart: F3 (strt) to restart the session.
```

TEXT How many data points

```
 How many points of data do you have ?
            5 --> 15 points
```

TEXT Wrong number of data pts

```
******* WARNING *******
You must have at least 5 points of data.
This may consist of the surface velocity,
bottom velocity and three other velocity
points.
```

TEXT Do you have the current profile

```
Do you have the current profile at this location.
    (current velocity at different depths)

  NOTE:  you need at least 5 points to qualify
```

TEXT What is the direction of the surface current

```
 What direction is the current ?
      N NE E SE S SW W NW
```

TEXT The deployment duration

```
 How many months is this mooring
 expected to survive ?

If less than 1 month enter 1 month
```

TEXT The seafloor topography

```
 What is the seafloor slope at the
location of the deployment ?  (degrees)
```

TEXT The seafloor material

```
 What is the Seafloor material ?
```

TEXT S1
Sand or Gravel
TEXT S2
Mud or Soft Clay
TEXT S3
Stiff Clay
TEXT S4
Very Stiff Clay or Glacial Till
TEXT S5
Soft Rock or Coral
TEXT S6
Hard, Monolithic Rock
TEXT S7
Boulders

TEXT Are there motion restrictions

```
 Are there motion restrictions on any
 of the instruments other than the
```

manufactures ?

TEXT How many instruments

How many instruments do you require ?

Please note that only scientific instruments are included such as current meters, hydrophones and depth recorders do not include items like acoustic releases.

TEXT Are there any ambient currents

Are there any ambient currents ?

TEXT The Instrument

Please select all that apply in this mooring design.
Use arrow keys (up) and (down) and <Return
to make each selection.
Use < F1 > (page) for more items.

EXPAND The Instrument

Please select all that apply:

Use the arrow keys to position the cursor at the desired of instrument <Return>. Then position the cursor to the next instrument. When done selecting use the F4 function key to finish.

Each of the categories of instruments/sensors shown in the previous screen are for determining which types ofspecific instruments the scientist needs in the mooring. Each category chosen will be followed by a list of components that are currently available and considered "State-of-the Art". If your specific instrument is not available select "Other". You will be prompted for your specific instrument's characteristics.

TEXT You are ready to continue analysis

The preliminary data has now been entered. If there has been any input error you must RESTART the session now!

Are you ready to proceed.

DISPLAY need info

You need to obtain the following:

- Title — What Depth are the Instruments
- Design Engineer — Are there motion restrictions with

```
- Project Number          a specific instrument beyond the
- Water Depth             manufactures restrictions
- Ambient Currents      - What is the Seafloor Material
  Direction             - What is the seafloor topography
  profile - depth       - How long is the mooring to be
         velocity              deployed (duration)
        direction
 - Number of Instruments
 - What are the Instruments

Not every point of information is necessary to produce
 a design.
```

```
DISPLAY something does not work

        **********     Warning      **********
                Something has gone wrong
END


************************************************************
************************************************************

             MOORING 2 KNOWLEDGE BASE

************************************************************
************************************************************

TITLE Mooring Design Analysis
!*************************************************
! This knowledge base selects the classification
! of the mooring and then activates the pertinent
! routines for analysis and component selection
!*************************************************

!-----------------------------------------------
! Shared Facts are found in file MOORSHAR.PRL
!-----------------------------------------------
$MOORSHAR.PRL

SIMPLEFACT We have the type of mooring
AND We have the bottom configuration
AND We have the top configuration
AND We have analyzed with restrictions
AND We have analyzed without restrictions
AND User satisfaction
AND We have no problems in launch transients
AND We have finished technical analysis
AND We must check restrictions
AND Failure information

NUMERIC Shark bite zone
AND Shark bite latitude zone
AND Steel Sphere maximum depth
```

```
STRING Problem classification
AND Failed instrument
AND Failed component

!-----------------------------------------------------
! The inference engine is to do an exhaustive search for
! all the possible avenues for the type of mooring,
! the type of bottom and top configuration, etc..
!-----------------------------------------------------
EXHAUSTIVE We have the type of mooring
AND We have the bottom configuration
AND We have the top configuration
AND We have analyzed with restrictions
AND We have analyzed without restrictions
AND We have finished technical analysis
AND User satisfaction
AND Failure information

!-----------------------------------------------------------
! The results of a successful mooring design will be stored
! in the text file mooring.dat.
!-----------------------------------------------------------
FILE MOORING.DAT

!-----------------------------------------------------
!                   GOAL
!-----------------------------------------------------
1. Designed mooring

!-----------------------------------------------------
!            Initialization Rule
!-----------------------------------------------------

RULE For starting the analysis
IF Shark bite zone := 2000
AND Shark bite latitude zone := 40
AND Steel Sphere maximum depth := 500
AND We have the bottom configuration
AND We have the top configuration
AND We have the type of mooring
AND The launch transients are found
AND FORGET Problem classification
AND FORGET Failure information
AND The Preliminary design is complete
AND We have finished technical analysis
OR We have no currents
!
!  Cost analysis of components
!
AND ACTIVATE COST.COM
DISK DATA.DAT
RETURN Problems in the cost
!
```

```
!  Preliminary design output listing of
!  parts & cost of mooring
!
AND ACTIVATE PRELIM.COM
DISK DATA.DAT
RETURN Problems in the preliminary design
AND User satisfaction
THEN Designed mooring

!=====================================================
!      Selection of Non-Acoustical Moorings
!=====================================================
!      Weak Currents
!-------------------------
RULE Type 1A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND Wire Rope
AND Instruments
AND We have the materials

RULE Type 2A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Wire Rope
AND Instruments
AND We have the materials

RULE Type 3A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Wire Rope
AND Instruments
AND We have the materials

RULE Type 4A mooring
IF  NonAcoustic array
```

```
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
AND Top Experiment Depth <= Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Wire Rope
AND Instruments
AND We have the materials

RULE Type 5A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Instruments
AND We have the materials

RULE Type 6A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Instruments
AND We have the materials

RULE Type 7A mooring
IF  NonAcoustic array
AND Weak currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Instruments
AND We have the materials

!--------------------------
!    Strong Currents
!--------------------------
RULE Type 8A mooring
```

```
IF   NonAcoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Wire Rope
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 9A mooring
IF   NonAcoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Wire Rope
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 10A mooring
IF   NonAcoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Wire Rope
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 11A mooring
IF   NonAcoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
AND Top Experiment Depth <= Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Wire Rope
```

```
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 12A mooring
IF  NonAcoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 13A mooring
IF  NonAcoustic array
AND Strong currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Strut Fairings
AND Instruments
AND We have the materials

RULE Type 14A mooring
IF  NonAcoustic array
AND Strong currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar Rope
AND Strut Fairings
AND Instruments
AND We have the materials

!=====================================================
!        Selection of Acoustical Moorings
!=====================================================
!      Weak Currents
!-----------------------
RULE Type 1B mooring
IF  Acoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
```

```
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Steel EM Cable
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 2B mooring
IF  Acoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Steel EM Cable
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 3B mooring
IF  Acoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Steel EM Cable
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 4B mooring
IF  Acoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
AND Top Experiment Depth <= Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Steel EM Cable
AND Hairy Fairies
AND Instruments
AND We have the materials
```

```
RULE Type 5B mooring
IF   Acoustic array
AND Weak currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 6B mooring
IF   Acoustic array
AND Weak currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 7B mooring
IF   Acoustic array
AND Weak currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Hairy Fairies
AND Instruments
AND We have the materials

!-----------------------------
!    Stong Currents
!-----------------------------
RULE Type 8B mooring
IF   Acoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Steel EM Cable
AND Strut Fairings
```

```
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 9B mooring
IF  Acoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth <= Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Steel EM Cable
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 10B mooring
IF  Acoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Steel EM Cable
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 11B mooring
IF  Acoustic array
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Steel Sphere maximum depth
AND Top Experiment Depth <= Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Steel EM Cable
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 12B mooring
IF  Acoustic array
```

```
AND Strong currents
AND Latitude < Shark bite latitude zone
AND Depth > Shark bite zone
AND Top Experiment Depth > Shark bite zone
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 13B mooring
IF  Acoustic array
AND Strong currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth <= Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

RULE Type 1[illegible]B mooring
IF  Acoustic array
AND Strong currents
AND Latitude > Shark bite latitude zone
AND Top Experiment Depth > Steel Sphere maximum depth
THEN We have the type of mooring
AND We can find the top configuration
AND We can find the bottom configutation
AND Kevlar EM Rope
AND Strut Fairings
AND Hairy Fairies
AND Instruments
AND We have the materials

!--------------------------------------------------
!       Bottom Mooring Configuration 1 & 2
!--------------------------------------------------
RULE For obtaining the bottom configuration
IF Weak currents
THEN Clump anchor
AND Chain above anchor
AND Nylon shock line
AND Wire rope anchor
AND Chain below acoustic release
AND Chain for backup retrieval
AND Glass balls for backup retrieval
AND Swivel
```

```
AND We have the bottom configuration
ELSE Mace anchor
AND Chain above anchor
AND Nylon shock line
AND Wire rope anchor
AND Chain below acoustic release
AND Chain for backup retrieval
AND Glass balls for backup retrieval
AND Swivel
AND We have the bottom configuration

!----------------------------------------------------
!       Top Mooring Configuration 1 & 2
!----------------------------------------------------
RULE For obtaining the top configuration
IF Weak currents
AND Top experiment depth > Steel sphere maximum depth
THEN Swivel
AND Chain for primary retrieval
AND Glass balls for primary retrieval
AND Polypropylene rope
AND Chain for recovery aids
AND Glass balls for recovery aids
AND Recovery aids
AND We have the top configuration

RULE For obtaining the top configuration
IF Weak currents
AND Top experiment depth < Steel sphere maximum depth
THEN Swivel
AND Chain below primary retrieval
AND Steel sphere
AND We have the top configuration

RULE For obtaining the top configuration
IF Strong currents
AND Top experiment depth > Steel sphere maximum depth
THEN Swivel
AND Chain below primary retrieval
AND Syntactic foam sphere
AND We have the top configuration

RULE For obtaining the top configuration
IF Strong currents
AND Top experiment depth < Steel sphere maximum depth
THEN Swivel
AND Chain below primary retrieval
AND Steel sphere
AND We have the top configuration

!================= Analysis Rules =======================
!
! These rules calculate the basic mooring configuration
! and then analyze and reconfigure the design until
```

```
! either the design is successful or due to limitations
! beyond the control of the system the design fails.
! If the design fails the system with the help of the
! designer recduces the constraints on the mooring
! design.
!
!==========================================================

!----------------------------------------------------------
!     Rules for determining Launch Transients
!----------------------------------------------------------
RULE For determining the Launch Transients
ACTIVATE LAUNCHT.COM
DISK DATA.DAT
SEND Mace anchor
SEND Clump anchor
SEND Chain for primary retrieval
SEND Glass balls for primary retrieval
SEND Polypropylene rope
SEND Chain for recovery aids
SEND Glass balls for recovery aids
SEND Recovery aids
SEND Chain below primary retrieval
SEND Steel sphere
SEND Syntactic foam sphere
RETURN We have no problems in launch transients
RETURN Problem classification
RETURN Failed component
IF We have solved launch transient problems
THEN The launch transients are found

RULE For problems in launch
IF NOT We have no problems in launch transients
AND Failure information
THEN We have solved launch transient problems
!
! Catastrophic Failure of the Mooring Design!!!
! A manditory restart is manditory.
!
AND CHAIN MOORING
ELSE We have solved launch transient problems

!----------------------------------------------------------
! Rule for deteriming the preliminary design configuration
!----------------------------------------------------------
RULE For setting up the preliminary design
ACTIVATE PRELIMIN.COM
THEN The Preliminary design is complete

!----------------------------------------------------------
!    Rules for the analysis success
!----------------------------------------------------------
RULE For analysis success
IF We have the profile
```

```
OR The profile is generated
AND We have analyzed with restrictions
OR We have analyzed without restrictions
AND Problem classification = Success1
THEN We have finished technical analysis

!-----------------------------------------------------------
!    Rules for analysis failure
!-----------------------------------------------------------
RULE For failure
IF We have the profile
OR The profile is generated
AND We have analyzed with restrictions
OR We have analyzed without restrictions
AND Problem classification <> Success1
AND Failure information
AND ACTIVATE REDO.COM
DISK DATA.DAT
SEND Problem classification
THEN We have finished technical analysis
!
! Design Failure. New parameters have been entered and
! the design restarted therefor various design criteria
! must be forgotten before cycling.
!
AND FORGET We have finished technical analysis
AND FORGET We have analyzed with restrictions
AND FORGET We have analyzed without restrictions
AND FORGET Problem classification
AND FORGET Failure information
AND CYCLE

!-----------------------------------------------------------
!    Rules for failure
!-----------------------------------------------------------
RULE For failure 1A
IF Problem classification = Failure1A
AND DISPLAY Failure screen #1A
AND Failure screen #1A1
THEN Failure information

RULE For failure 1B
IF Problem classification = Failure1B
AND DISPLAY Failure screen #1B
AND Failure screen #1B1
THEN Failure information

RULE For failure Launcht
IF Problem classification = Flauncht1
AND Failure screen Flaunch1
THEN Failure information
!-----------------------------------------------------------
!    Rule for controlling the analysis procedures
!-----------------------------------------------------------
```

```
RULE For design analysis with restrictions
IF We have the motion restrictions
AND ACTIVATE ANALYZE.COM
DISK DATA.DAT
SEND We have the motion restrictions
SEND The seafloor topography
SEND The deployment duration
RETURN Problem classification
RETURN Failed instrument
RETURN Failed component
THEN We have analyzed with restrictions

RULE For design analysis without Restrictions
IF We have no motion restrictions
AND ACTIVATE ANALYZE.COM
DISK DATA.DAT
SEND We have the motion restrictions
SEND The seafloor topography
SEND The deployment duration
RETURN Problem classification
RETURN Failed instrument
RETURN Failed component
THEN We have analyzed without restrictions

!-------------------------------------------------------
!  Rules for a satisfied and unsatisfied user/design
!-------------------------------------------------------
RULE User satisfied 1
IF More than one run
AND User satisfied
AND ACTIVATE SAT.COM
DISK DATA.DAT
SEND More than one run
THEN User satisfaction

RULE User satisfied 2
IF NOT More than one run
AND User satisfied
AND ACTIVATE SAT.COM
DISK DATA.DAT
SEND More than one run
THEN User satisfaction

RULE User not satisfied 1
IF NOT User satisfied
AND Want to save run
AND ACTIVATE UNSAT.COM
DISK DATA.DAT
SEND Want to save run
AND Reentered constraints
THEN User satisfaction
!
! User unsatisfied. New parameters have been entered and
! the design restarted therefor various design criteria
```

```
! must be forgotten before cycling.
!
AND FORGET We have finished technical analysis
AND FORGET We have analyzed with restrictions
AND FORGET We have analyzed without restrictions
AND FORGET Problem classification
AND FORGET Failure information
AND CYCLE

RULE User not satisfied 2
IF NOT User satisfied
AND NOT Want to save run
AND Reentered constraints
THEN User satisfaction
!
! User unsatisfied. New parameters have been entered and
! the design restarted therefor various design criteria
! must be forgotten before cycling.
!
AND FORGET We have finished technical analysis
AND FORGET We have analyzed with restrictions
AND FORGET We have analyzed without restrictions
AND FORGET Problem classification
AND FORGET Failure information
AND CYCLE

!-----------------------------------------------------
!          RULE For reentering constraints
!-----------------------------------------------------
RULE For reentering constraints
IF NOT User satisfied
AND ACTIVATE CONSTR.COM
THEN Reentered constraints

!=====================================================
!                TEXT OUTPUT
!-----------------------------------------------------
TEXT User satisfied
```

The basic design and costs have been presented Are you satisfied with the solution ?

TEXT More then one run

Whether the design is satisfactory or not will other runs be necessary ?

TEXT Want to save run

Want to save run ?

DISPLAY Failure screen #1A

THE DESIGN HAS FAILED !!! (#1A)

Causes: With this failure the mooring could not be designed due to the forces on the mooring cause a configuration which is unable to meet the manufactures specifications. The instrument >>[Failed instrument]<< is the cause of failure You may need to select an instrument which has less critical constraints.

The method utilized in the mooring design component selection is an iterative process. Starting with the smallest sized component and proceeding to larger sizes until a satisfactory component is selected. If the data base doesn't contain a size strong enough the design will fail

Next Page please => F1 <=

Page 2 of 3

There are two possible solutions which can be done to alleviate the problem: (1) You can select another instrument which may have looser constraints, allowing for a successfully completed design, or (2) the database of the specified failure component >>[Failed component]<< can be added to with a stronger component which may satisfy the design.

If you desire to enter new data into the database PRESS >> F1 << for instructions.

If you desire to select another instrument PRESS >> F2 << and ENTER >> True << on the next menu.

Page 3 of 3

If you decide to add to the data base be sure to obtain all information necessary to complete a data base addition. See manual on data base additions. Failure to to obtain all necessary information will prevent an addition.

PRESS >> F2 << to continue and PRESS >> Failure << at the next menu.

TEXT Failure screen #1A1

Do you wish to select another [Failed instrument] and attempt completion of this design ??

TEXT Failure screen #1B1

```
Do you wish to change previously entered constraints?
```

DISPLAY Failure screen #1B

```
                THE DESIGN HAS FAILED !!!              (#1B)

Causes: With this failure the mooring could not be
        designed due to the forces on the mooring cause
        a configuration which is unable to meet your
        user entered constraints and specifications on
        the specified instruments.  The method utilized
        in the mooring design component selection is an
        iterative process. Starting with the smallest
        sized component and proceeding to larger sizes
        until a satisfactory component is selected.  If
        the data base doesn't containt a size strong
        enough the design will fail.

   Next Page please       => F1 <=
```

```
                      Page 2 of 3

The design failed because the >>>[Failed component]<<<
database did not contain a size which was able to
accomodate the design at hand.

There are two possible solutions which can be done to
alleviate the problem: (1) You can reduce your instrument
constraints which may allow a successful design to be
completed, or (2) the database of the specified
instrument can have a component added to it which may
satisfy the design.

If you desire to enter new data into the database
PRESS >> F1 << for instructions.

If you desire to reduce your constraints PRESS >> F2 <<
and ENTER >> True << on the next menu.
```

```
                      Page 3 of 3

If you decide to add to the data base be sure to obtain
all information necessary to complete a data base
addition.  See manual on data base additions. Failure to
to obtain all necessary information will prevent an
addition.

 PRESS >> F2 << to continue and PRESS >> Failure << at
```

```
the next menu.
```

TEXT Failure screen #1B1

```
Do you wish to change previously entered constraints?
```

TEXT Failure screen Flaunch1

```
        THE DESIGN HAS FAILED !!!      (Launch Transients)

Probable Causes: The weight of all of the instruments
   combined exceeds the strength of the largest mooring
   component >>[Failed component]<< the failure
   is due to the large amount of flotation needed to
   support the mooring.

To remedy the situation it is suggested to reduce the
number of instruments on the line and if necessary deploy
another mooring with those instruments.

The design at the present cannot continue.

Do you wish to restart the mooring design to design with
fewer instruments ?? >> TRUE <<

If you wish to terminate the session then >> FALSE <<
```

END

```
***********************************************************
***********************************************************

            MOORING KNOWLEDGE BASE SHARED VALUES

***********************************************************
***********************************************************

!
! This file contains the shared values for the MOORING
! knowledge base it is for MOORING2 and other Knowledge
! bases.
!
SHARED NUMERIC Depth
AND NUMERIC Top Experiment Depth
AND NUMERIC bottom experiment depth
AND NUMERIC Latitude
AND NUMERIC Longitude
AND NUMERIC How many instruments
AND NUMERIC The seafloor topography
AND NUMERIC The deployment duration
AND STRING Title
AND STRING Designer
```

```
AND STRING Contract#
AND SIMPLEFACT NonAcoustic array
AND SIMPLEFACT Acoustic array
AND SIMPLEFACT Strong currents
AND SIMPLEFACT Weak currents
AND SIMPLEFACT We have the motion restrictions
AND SIMPLEFACT We have no motion restrictions
AND SIMPLEFACT The profile is generated
AND SIMPLEFACT We have the profile
AND NUMERIC Number of Instruments
AND NUMERIC Length of Instrument
AND NUMERIC Area of Instrument
AND NUMERIC Weight of Instrument
AND NUMERIC Buoyancy of Instrument
AND NUMERIC Maximum depth of Instrument
AND NUMERIC Drag coefficient of Instrument
AND NUMERIC Maximum tension
AND NUMERIC Cost of Instrument
AND STRING Type of Instrument
!
```

VITA

STEPHEN LATHROP WOOD

PROFESSIONAL OBJECTIVE:		**Mechanical Engineering-Ocean Engineering** position in underwater Robotics, Expert System Design of Ocean Systems, with Research and Development pertaining to Ocean Engineering.
EDUCATION:		**M.S. Ocean Engineering**, 1987 University of Miami, Rosenstiel School of Marine and Atmospheric Science Coral Gables, Fla. 33146
		B.S. Mechanical Engineering, 1983 University of Rhode Island Kingston R.I. 02881
EXPERIENCE:		
	5/86 to 8/87	**Ocean Engineer Research Assistant** - RSMAS Developed and Submitted to OMAE '88 conference "Architecture of an Expert System for Oceanographic Mooring Design."
	9/83 to 7/85	**Mechanical Engineer** - COMPUTER LINK CORPORATION. Design, develop and implement new designs on State of the Art computer peripheral equipment: 3000 Computer Tape Evaluator, Sorc 800 data processor. Project leader for the redesign of the 600 series Computer Disk Inspector. Wilmington, Mass. 01887 (617) 657-8820
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END
JAN.
1988
DTIC